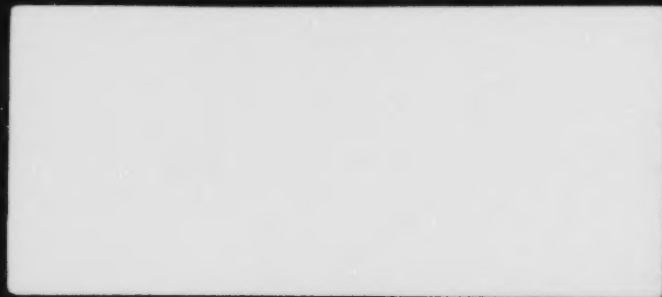


Final Report



A project under the Canada
New Brunswick Conservation
and Renewable Energy
Demonstration Program

SMALL SCALE WOOD CHIP FUEL

29

HARVESTING AND PROCESSING

FACULTY OF FORESTRY
UNIVERSITY OF NEW BRUNSWICK
February, 1985

CREDA PROJECT #2023

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Through over 100 demonstration projects in New Brunswick, a wide variety of conservation and renewable energy technologies have proven to be technically sound and economically attractive. These demonstration projects should now provide a catalyst for commercialization and lead to widespread adoption of many of these proven technologies.

This final report is based on a project which was financially supported by the Energy Demonstration Program. For further information on other demonstration projects funded in New Brunswick under this program, contact:

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ACKNOWLEDGEMENTS

This Project was the result of the cooperation and efforts of many people. Without these people, the Project could not have been carried out. Dr. Hank Blenis and Mr. Bert Jeffrey of the Maritime Forest Ranger School gave encouragement and all kinds of physical support including use of equipment, repair of equipment and help selecting blocks to be harvested. Mr. Perley Wilkins gave much useful advice, and assisted with men, shop time and equipment. To these people, and to others such as suppliers and truckers, we give our hearty thanks.

Marc Schneider

Tony Short

Jeremy Rickards

John Kipping

PERSONAL NOTE

I thank God for what I perceive to be his guiding of the work and my involvement in it. I am also thankful for the personal interactions and friendships which resulted from the Project. I hope the results will ultimately help make life better for the people of New Brunswick, the rest of Canada and the rest of the world.

Marc Schneider,

Senior Principal Investigator

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EXECUTIVE ABSTRACT

The objectives of the Fuelwood Chip Project were to evaluate and demonstrate (1) several small scale methods of harvesting small [200 mm (8 in.) or less] trees and chipping them for fuel and (2) a method of processing such chips for use in dry chip-fired, residential, central heating appliances.

Nine field trials were conducted using various combinations of equipment. The trials consisted of two slash reclamation tests, two thinning tests, and five clear-cutting tests. The tests were conducted on various sites ranging from 0.2 to 1.8 ha (0.5 to 4.5 acres) in area. The trees harvested were small; the average stem diameter was 70 mm (2.75 in). Every site was measured before harvest to predict the amount of biomass present. The mass of biomass harvested was determined by weighing after chipping. The amount of material obtained from the sites varied from 50% to 80% of the biomass present. Harvesting consisted of chain-saw felling and delimbing, skidding to roadside using winch-equipped farm tractors, a skidder (used in three trials) or a small, portable winch (Yankee Yarder, used in one trial), and then chipping into a 30 cu m (40 cu yd) portable bin. The full bins were taken to the processing facility where they were weighed and dumped.

At the processing facility, the chips were reclaimed and dumped into a metering hopper which fed them gradually onto a vibratory screen. The chips which passed the screen fell onto a belt conveyor which delivered them to the drying chamber. The chamber has a capacity of 45 cu m (60 cu yd) and is fitted with a fan which blows air up through the perforated floor and the 2.4 m (8 ft) depth of chips. Dried chips were moved from the chamber into protected storage by the same bucket-equipped tractor used to reclaim them. Costs to harvest, process and deliver chips were strongly influenced by labour costs and the

basis upon which the equipment was acquired. Cost per 20% mc tonne ranged from \$38.67 to \$198.28. The lowest cost was achieved when chip harvesting was integrated with silvicultural activities.

SOMMAIRE-RECOMMANDATION

Les objectifs du projet de ramassage de débris de bois combustibles consistaient à évaluer et à démontrer (1) plusieurs méthodes à petite échelle de récolte d'arbres de faible diamètre (200 mm (8 po) ou moins) et de déchiquetage de ces derniers en copeaux de bois combustibles et (2) une méthode de traitement de ces copeaux en vue de leur consommation dans des appareils de chauffage résidentiel central aux copeaux de bois sec.

Neuf essais sur le terrain ont été réalisés au moyen de diverses combinaisons d'outillage. Il y eut deux essais de récupération des débris, deux essais d'éclaircie forestière et cinq essais de coupe à blanc. Les terrains choisis variaient de 0,2 à 1,8 ha (0,5 à 4,5 acres). Les arbres récoltés étaient de faibles dimensions, le diamètre moyen se situant à près de 70 mm (2,75 po). Chaque emplacement a été mesuré avant la récolte afin de pouvoir prédire la quantité de biomasse à ramasser. La masse du matériel récolté était pesée après sa transformation en copeaux. La quantité obtenue aux divers emplacements variait de 50 % à 80 % du total de la biomasse présente. Les opérations d'exploitation comprenaient l'abattage et l'ébranchage au moyen de scies mécaniques, le débardage jusqu'au bord du chemin au moyen de tracteurs agricoles munis d'un treuil, d'une débardeuse (utilisée pour trois essais) ou d'un petit treuil portatif (Yankee Yarder, utilisé pour un essai), et enfin la transformation du

matériel en copeaux, ces derniers étant ensuite placés dans des contenants portatifs de 30 m³ (40 verges cubes). Une fois pleins, ces silos étaient transportés à l'installation de traitement où ils étaient pesés et vidés de leur contenu.

Une fois à l'installation de traitement, les copeaux étaient recueillis et placés dans une trémie de mesurage puis transférés graduellement sur un crible vibrant. De là, ils tombaient sur un transporteur à bande qui les transférait dans un séchoir d'une capacité de 45 m³ (60 verges cubes) muni d'un ventilateur faisant circuler l'air à travers le plancher perforé et 2,4 m (8 pieds) d'épaisseur de copeaux. Une fois séchés, les copeaux étaient transportés dans un lieu d'entreposage protégé au moyen du même système de tracteur muni d'un godet comme celui qui avait été utilisé pour le ramassage. Les coûts de la récolte, du traitement et de la livraison des copeaux était fortement influencé par les coûts de la main-d'oeuvre et du mode d'acquisition de l'outillage. Le coût par tonne de copeaux à 20 % d'humidité variait de 38,67 \$ à 198,28 \$. Le coût le plus faible était obtenu lorsque le ramassage des copeaux était intégré à d'autres activités sylvicoles.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The Chip Heating Project set out to demonstrate harvesting, processing and transportation of fuel wood chips using small-scale equipment. The main goals were:

1. to show technical feasibility,
2. to have operating hardware available for viewing,
3. to use, where possible, already-available small-scale technology,
4. and to document experience operating the system.

Equipment and manpower used by the Project, is given in Table 0.1.

Harvesting documentation included measuring forest biomass, amount harvested, amount of chips produced per unit of time by the various men and machines, and gasoline, diesel oil and electricity use. Similar measurements were made for the processing and transportation phases of the Project system. Costs were also recorded for each phase.

The Project carried out pickup of slash after a commercial clearcut, thinning operations, and clearcuts of sub-commercial poplar-birch stands. The harvesting operations accomplished, and the equipment used in each case, are summarized in Table 0.3. Table 0.4 shows that biomass recovered was less than that estimated to be on the ground. This illustrates differences between total biomass and recoverable biomass.

Average productivity experience for felling and forwarding and for chipping are given in Table 0.5. For perspective, approximately 10 to 12 tonnes of chips at 20% moisture content (dry basis) would be needed to heat a typical single-family home for a winter in climates like New Brunswick.

Gasoline and diesel oil used to carry out the operations was measured and compared to the higher heating value of the chips produced. The results are

summarized in Table 0.6. Energy required to transport the chips is, of course, dependent on distance and load size. Where transportation distance is short, such as in the Project, the energy required to transport the chips makes up a small proportion of total fuel used. The relationship found between chip combustion energy and transportation distance, using approximately 30 cubic meter containers, is given in the footnote to Table 0.6. In the Project, 92 kilometers would be the point where it would take as much energy to transport the chips as would be yielded upon their combustion. The smaller ratio (13 to 1) is from the more bulky, difficult-to-forward slash while the higher ratios (47 to 1) without transportation and 41 to 1 after transportation) are from clear-cuts of small-sized hardwoods.

The Project chips were screened on a vibratory conveyor which was also part of the drying bin loading system. The drying bin is a perforated-bottom structure designed using principles developed in agricultural grain drying. A grain-drying fan forced air through the chips, causing them to dry. The dry chips were unloaded and carried to roofed storage using a tractor bucket loader. Some of the particulars of the chip drying experience are given in Table 0.7. Table 0.8 summarizes Project measurements on roundwood-to-chip conversions and chip bulk densities.

In this small-scale chip production system, the labour requirement was high. The high labour input resulted from low productivity during harvesting the small-sized material, from the need to feed the chipper manually, and from the low capacity of the chipper. The labour cost contributed a large part of total chip production cost experienced by the Project. Considerable cost variation was found among the blocks harvested. This illustrates the situation-specific nature of costing. Table 0.9 summarizes Chip Project costs.

The Chip Project demonstrated the technical feasibility of small-scale

chip production. The results of the work suggest, however, that small-scale wood chip production is not now commercially attractive as a single-purpose activity, but that it might be successfully undertaken as part of a multi-purpose harvesting and forest management strategy, especially for small woodlot owners. Higher alternate energy costs should increase financial attractiveness of wood chip fuel. Small-scale production of wood chips does appear to be financially attractive to those who could do it themselves, similarly to the way firewood is produced. It would be especially attractive to those who already own most of the equipment and facilities needed for production and storage, such as farmers.

Experience with the Chip Project suggests that chipping and drying are currently bottlenecks in our system. Also, efficient, adaptable chip handling and delivery systems would make the fuel potentially accessible to more users. A chipper that was mechanically-fed and had a somewhat higher raw material size and throughput capacity should remove the chipping bottleneck, but that would probably put it into a category where it could not be operated by a farm tractor. The chip drying speed and energy efficiency could probably be improved by using thinner chip beds and smaller fans. This would require more sophisticated handling systems in order to move the chips through more rapidly, however. A device which could quickly and flexibly move chips about, and vehicles which could easily deliver chips to a variety of storage sites would help the supplier meet consumer needs with a minimum of difficulty and labour. All of these technologies require further work in order to optimize them, and to increase the overall efficiency and convenience of the system the Chip Project demonstrated.

TABLE 0.1 SCALE OF OPERATIONS

Element	Equipment	Approximate Capital Cost \$	Number of Men
Harvesting	Tractor	\$10,000	2
	Winch	5,000	
Chipping	Tractor	12,000	2
	Chipper	12,000	
Transport	RO-RO	2,500	1
Screening	Conveyor-Screen		
Drying	Bin	40,000	2
Bulk Storage	Building		
Home Delivery	Dump Truck	10,000	1
Home Storage		1,000	1

TABLE 0.2 EQUIPMENT USED TO HARVEST STANDS

Operation	<u>Machines For:</u>	
	Forwarding	Transport
Slash 1	Skidder	Farm Trailer
Slash 2	Farm Tractor and Winch	Farm Trailer
Thin 1	Farm Tractor and Winch	3-Ton Dump Truck
Thin 2	Yankee Yarder	Ro-Ro*
Clear 1	Farm Tractor and Winch (same tractor to chip)	Ro-Ro
Clear 2	Skidder	Ro-Ro
Clear 3	Skidder	Ro-Ro
Clear 4	Farm Tractor and Winch (another tractor to chip)	Ro-Ro
Clear 5	Same as Clear 4	Ro-Ro

* Roll On - Roll Off Container, 24 or 27 Cu M

TABLE 0.3 DESCRIPTIONS OF STANDS HARVESTED

Designation	Location	Area (Hect.)	Average Stem Diam. (cm)	Average Stems/Hect.	Tonnes/ Hect.**
Slash 1	Private Woodlot	0.7	-	-	
Slash 2	Private Woodlot	0.4	-	-	
Thin 1	UNB Woodlot	0.8	5.6*	9435*	87.5
Thin 2	UNB Campus	1.8	13.9*	3839*	241.7
Clear 1	CFB Gagetown	0.2	9.2	5800	84.3
Clear 2	CFB Gagetown	0.2	7.0	4200	115.7
Clear 3	CFB Gagetown	0.2	7.2	7800	138.7
Clear 4	UNB Woodlot	0.2	7.2	5400	101.2
Clear 5	UNB Woodlot	0.2	6.9	3600	105.2

* Average for stand, but not material harvested

** Ker's (1980) biomass equations

TABLE 0.4 COMPARISON OF CHIPS PRODUCED TO BIOMASS ESTIMATES FROM SAMPLING

Operation	OD Biomass Estimate, Tonnes/Hect.*	OD Tonnes Chips Produced/ Hect.	% Produced
Thinnings	21.3	17.2	81
Clearcuts	109.0	55.3	51

* Ker's (1980) biomass equations

TABLE 0.5 PRODUCTIVITY OF OPERATIONS

Element	20% Tonnes/Hr		Cubic Meters*/Hr	
	Man	Machine	Man	Machine
Felling and Forwarding	0.15	0.40	0.75	2.00
Chipping	0.36	0.77	1.80	3.85
	Hrs/20% Tonne		Hrs/Cubic Meter	
	Man	Machine	Man	Machine
Felling and Forwarding	6.67	2.50	1.33	0.5
Chipping	2.78	1.30	0.56	0.26
	Cords**/Hr			
	Man	Machine		
Felling and Forwarding	0.20	0.50		
Chipping	0.50	1.00		

* At 0.2 tonne/cu m or 12 lbs/cu ft

** 1.3 tonnes/cord at 20% mc

TABLE 0.6 RATIOS OF HIGHER HEATING VALUE OF CHIPS PRODUCED TO FUEL USED TO HARVEST, CHIP AND TRANSPORT.

Element	Energy Ratios		% Energy
Harvesting	13:1	13:1 to 41:1	44
Chipping	47:1		56
Transport			—*

* % of total energy in chips required for transport = $0.92 \times \text{km}$

TABLE 0.7. FORCED AIR DRYING EXPERIENCE

Element	Specifics	Values
Forced Airflow Through 2.5 M (8 FT) of Chips	5 HP Axial Fan, 500 PA (2 In. WG)	0.22 Cu M/Sec/Sq M (41.5 Cfm/Sq Ft)
Ambient Air Volume Required	To Evaporate 1 KG of Water	418 Cu M (14,761 Cu Ft)
Ratio to Water Evaporation Energy to Fan Energy	May to July, 5 HP Fan	4:1

TABLE 0.8 DESIGN INFORMATION SUMMARY

Element	Specifics	Values
As-Produced Chip Bulk Density	Hardwoods Softwoods	320 Kg/Cu M (20 Lbs/Cu Ft) 250 Kg/Cu M (16 Lbs/Cu Ft)
20% MC Chip Bulk Density	Hardwoods Softwoods	240 Kg/Cu M (15 Lbs/Cu Ft) 200 Kg/Cu M (12 Lbs/Cu Ft)
Average Volume Expansion Ratios	Solid Wood to Chips Cordwood to Chips	2.6 1.7

TABLE 0.9 AVERAGE COST PER 20% MC TONNE

Harvesting Type	Fixed	Operating	Labour	Transport	Total
Slash	\$26	\$35	\$74	\$19	\$154
Thin	6	9	53	10	78
Clear	31	31	66	16	144
Thin*	10	11	0	18	39
Drying, Processing, Delivery**	11	3	10	8	32

* Excludes costs assigned to silviculture.

** 12 km radius.

1.0 Introduction

1.1 Background

From 1978 to 1982, a UNB wood chip stoker demonstration project, funded by the New Brunswick Energy Secretariat, was carried out by Prof. C.A. Short and Dr. M.H. Schneider. This furnace project demonstrated the expected benefits from firing wood chips-namely, that the stokers are more convenient and less polluting than chunkwood burners. In addition, they will burn chips produced from many types of woody material, thereby raising the possibility of using forest residues and thinnings for fuel instead of higher-quality wood which might better be used for wood products. These results are documented in Schneider and Short 1982.¹

With the successful furnace demonstration, chip supply became the next logical area to consider. The supply of pulp chips is an old technology, but there is little experience in North America with small-scale production and supply of fuel chips suitable for small heating systems. Although the Scandinavian countries have been pioneers in fuel chip heating, their experience is not directly applicable to North America. Prince Edward Island has done some small-scale harvesting and distribution of fuel wood chips, but no accompanying cost data or man and machine-hour data is available. A research group at the University of Maine at Orono has experience with drying and storing pulp chips to be used for home heating, and through our continued close contact with them, we have exchanged much helpful information.

This fuel chip supply demonstration project was designed to illustrate some harvesting, screening and drying, and distributing methods which are low in capital cost and which use, as much as possible, standard components and technologies or adaptations already in use. In particular, there are forest harvesting machines available which are suitable for small-scale

The flowchart illustrates the wood chip supply chain across seven phases, separated by horizontal dotted lines:

- PHASE I: HARVESTING** - Includes four circular nodes: *residue*, *thinning*, *clearing*, and *salvage*.
- PHASE II: CHIPPING** - Includes two circular nodes: *chipping* and *chipping*. A triangular node *wet chips* is also present. Arrows from Phase I lead to these nodes.
- PHASE III: DRYING** - Includes two circular nodes: *drying* and *drying*. Arrows from Phase II lead to these nodes.
- PHASE IV: STORAGE** - Includes two triangular nodes: *storage* and *storage*. Arrows from Phase III lead to these nodes.
- PHASE V: WHOLESALE** - Includes a triangular node *dry chips* and the text *Wholesaler*. An arrow from Phase IV leads to this node.
- PHASE VI: RETAILING** - Includes the text *Retailers*. Multiple arrows from Phase V lead to this phase.
- PHASE VII: CONSUMER** - Includes the text *Consumer*. Multiple arrows from Phase VI lead to this phase.

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systems, and drying and handling technologies used in agriculture which seem adaptable to chip drying and handling.

Another aim of the project was to stimulate the chip supply infrastructure. We anticipated gaps in the technology to produce chips and in the facilities to store and process them. It was our intention to provide assistance in the form of design expertise and project experience to New Brunswick manufacturers and other local business people interested in supplying the missing parts.

1.2 Project Objectives

The project objective was to demonstrate, within limits of available resources, the elements making up the chart in Figure 1.1. We intended to have examples of each phase in place and operating for interested persons to see. We also intended to obtain operating experience with each phase so that data would be available for others to use. Capital and operating costs as we experienced them, and processing times, is helpful information for seriously interested persons.

The project concentrated on the small-scale - that is, the scale which could be undertaken with readily-available farm, or small logging, equipment. The only additional piece of equipment needed is a chipper to fit on the three-point hitch of a farm tractor. Should a small-scale producer not have access to full-year storage space with drying capability on the premises to be heated with chips, some central drying, screening and storage facility is necessary. In order to make best use of capital, such a facility should be somewhat larger scale. It was our intention to build and operate a facility small enough to fit into a small-scale operation, yet large enough to serve as an example for larger scales.

1.3 Project personnel

The project personnel and responsibilities are:

<u>Person</u>	<u>Responsibility</u>
Dr. M.H. Schneider, WST	Principal investigator: Project direction, management and overseeing.
Prof. C.A. Short, PEng	Principal investigator: Project direction.
Prof. E.J.P. Rickards, PEng	Principal investigator: Project direction.
Mr. J.E. Kipping, PEng	Project Engineer: Project engineering, and day-to-day operations.

Mr. Kipping was hired because the three principal investigators have day-to-day responsibilities which do not allow good continuity, detailed planning, personnel overseeing, data collection, and data reduction. A project of this magnitude requires someone whose major work responsibility is the project on a daily basis. An engineer has the technological background and analytical capabilities necessary for this task.

In addition to the personnel listed in the table, Graham Savage, Michael Thorne and Stephen Henley, all graduates of the UNB Faculty of Forestry with forestry experience, carried out the harvesting work and supplied much of the labour for building the drying facility. Mr. Savage was involved in the slash pickup, thinning and clearcutting operations,

acting as foreman, data-taker and professional forester. Forest Engineering technologist William Edgar made many of the refinements to the processing centre. All of these persons contributed their ideas and energy to the project and were important in carrying it out.

2.0 Wood Chip Characteristics

2.1 Introduction

The wood chips produced in this project were nominally 11 mm (1/4 in) long. This size has become standard in the Scandinavian countries for use in small heating plants, and most Scandinavian small-scale chippers are designed to produce this size. Some dust and large particles are also produced with the chips. Fines can be irritating to respiratory systems, and large particles can impede chip flow through conveyors. Anyone using, producing or transporting fuel wood chips should become familiar with some of the physical properties of the chips, including weights, densities, and comparisons to more familiar fuels. This section attempts to provide such information, based upon the results of the demonstration.

2.2 Data Acquisition

Chip moisture content measurements were made frequently throughout the harvesting demonstrations. In all but the last operation, samples from chips were obtained as they were produced. In the last operation, (THIN 2), the MC of chips produced over 125 identified trees was obtained. In the clearcuts, we already had a good estimate of species mix from the forest inventory because all trees were harvested. In the thin, the sampling of

trees allowed species mix to be determined and also gave average MC values for some species which are not listed in the literature.

In the early operations, (SLASH 1 and THIN 1), chip bulk densities were determined by weighing small, known-volume containers. For the remaining operations, large bulk containers were used for transporting chips. Each load was weighed while on the transporting truck, using a highway weigh scale. Then, after emptying, the truck and container was tared. Container volumes were already known (if not full, the volume of their contents was measured). The weights and the volumes together gave the data necessary for calculating density.

With weight and MC known, dry wood content, and therefore, weights at any MC, could be calculated. We chose 20% MC as the standard because chips at this MC burn well in dry-fuel burners and store well in covered storage, and because this MC can be easily reached in ambient-air drying during the summer months.

Where we did not have data from our own work about species MC or specific gravity, values from the Eastern Forest Products Laboratory (Kennedy 1965 and Cech & Pfaff 1977) were used. These were obtained by sampling a large number of trees in Eastern Canada, and should be representative of the woods we harvested. Conversions from specific gravities to densities were accomplished using the tables provided by the US Forest Products Laboratory (US FPL 1974).

2.3 Results and Relationships

Table 2.1 gives the average MC and chip density for each of the harvested stands. Using the species composition of the material harvested, the weighted specific gravity of the wood in the stand was calculated (Table 2.2). This allowed the density of the solid wood to be obtained from the US

Table 2.1. Relationships among solid wood, stacked wood and chip densities all at MC as produced.

Designation	Species	Green Tonnes Chips Produced	Average MC	Chip Bulk Density kg/m ³	Solid Wood Density kg/m ³	Cordwood Density kg/m ³	Volume Expansion to chips from Solid Wood	Cordwood
SLASH 1	fir-spruce	15.8	45	228	500	312	2.2	1.4
THIN 1	red maple	17.9	44	263	748	468	2.8	1.8
CLEAR 1	poplar-maple-birch	21.4	91	320	880	550	2.8	1.7
2	birch-poplar-fir	21.4	88	340	827	517	2.4	1.5
3	poplar-maple-birch	15.7	87	325	860	538	2.6	1.7
4	beech-fir	20.6	78	349	940	588	2.7	1.7
5	beech	23.2	81	328	1,060	662	3.2	2.0
THIN 2	<u>spruce-fir-larch</u>	49.0	73	<u>271</u>	635	397	<u>2.3</u>	<u>1.5</u>
	Averages: hardwoods			321			2.8	1.9
	softwoods			250			<u>2.2</u>	<u>1.5</u>
					Overall		2.6	1.7

See Table 2.2 for derivation.
Solid wood to cordwood = $80 \text{ ft.}^3 \text{ solid wood/cord} = 0.625$
 $\frac{128 \text{ ft.}^3 \text{ space/cord}}$

Table 2.2. Density relationships of solid wood, cordwood and chips.

	Species	%	MC	Gg ¹	Weighted Gg	Solid wood density ² kg/m ³	Density ³ of Cord-wood ³ kg/m ³	Measured chip density kg/m ³	Relative density chips to solid wood	Relative density chips to cord-wood
SLASH 1	fir	80	45	.34	.35	500	312	228	0.45	0.71
	spruce	20		.38						
THIN 1	r. maple	100	44	.52	.52	748	468	263	0.36	0.56
CLEAR 1	r. maple	50		.52						
	fir	29	91	.34	.46	880	550	320	0.36	0.59
	w. birch	21		.51						
2	poplar	64		.37						
	r. maple	23	88	.52	.42	827	517	340	0.42	0.67
	w. birch	13		.51						
3	poplar	32		.37						
	r. maple	30	87	.52	.46	860	538	325	0.38	0.59
	w. birch	29		.51						
	spruce	9		.38						
4	beech	75	78	.59	.53	940	588	349	0.37	0.59
	fir	25		.34						
5	beech	100	81	.59	.59	1,060	662	328	0.31	0.50
THIN 2	spruce	44		.38						
	fir	37		.34						
	larch	8	73	.48	.37	635	397	271	0.43	0.67
	cedar	5		.30						
	r. maple	3		.52						
	w. pine	3		.36						
						Averages:	Hardwoods		0.53	
							Softwoods		0.67	
						Overall		0.38	0.59	

¹Kennedy, 1965 (wt. oven-dry, volume green).²U.S. For. Prod. Lab. 1974.³80 ft³/cord in 128 ft³ of space or 0.625 x solid wood density

Table 2.3. Relationships among species, specific gravity, MC, density and weight per cord.

Species	Specific Gravity		OD ¹	Green MC ³	Density, kg/m ³		Tonnes/cord ⁴	
	Basic ¹	20% ²			20%	Green	20%	Green
Beech	0.59	0.62	0.70	70	743	998	1.7	2.2
Sugar Maple	0.60	0.63	0.70	68	750	1010	1.7	2.3
Yellow Birch	0.56	0.59	0.65	69	707	940	1.6	2.1
Red Maple	0.52	0.54	0.59	70	647	884	1.5	2.0
White Birch	0.51	0.53	0.59	73	634	875	1.4	2.0
Tamarack	0.48	0.50	0.54	104	599	980	1.4	2.2
Poplar	0.37	0.38	0.42	104	455	740	1.0	1.7
E. Spruce	0.38	0.39	0.42	72	468	654	1.0	1.5
White Pine	0.36	0.37	0.38	90	451	683	1.0	1.5
Balsam Fir	0.34	0.35	0.37	118	420	748	0.9	1.7
White Cedar	0.30	0.31	0.31	93	372	594	0.8	1.3
Averages - Hardwoods (Beech to Tamarack)					680	984	1.6	2.1
Softwoods (Poplar to Cedar)					433	684	0.9	1.5
Overall							1.3	1.9

¹Kennedy 1965.

²U.S. Forest Prod. Lab. 1974 (P3-13 and 3-25).

³Cech. and Pfaff 1977.

⁴Cord = 80 ft³ or 2.26 m³ of solid wood.

Forest Products Laboratory tables. Cordwood is normally about 80 ft³ in the 128 ft³ cord, thus giving a solid wood ratio of 0.625. Both of these values for each stand are given in Table 2.1. Comparison of these latter values with the measured chip densities allowed calculation of the volume expansion factors in the last two columns of the table. From stacked roundwood, hardwood chips expand in volume almost twice, while softwoods expand about 1.5 times.

Table 2.3 gives the information necessary to determine the weight per cord of the species we harvested, in both the 20% MC and green condition. These values and their densities are given in the table.

Figures 2.1 to 2.8 are based upon the material given in Tables 2.1 to 2.3. They are designed to allow various conversions to be easily made. The conversions are tonnes of chips to cords of roundwood, cubic meters of chips to cords of wood, litres of oil to cubic meters of chips, litres of oil to tonnes of chips, kilowatt hours of electricity to tonnes of chips, and cubic meters of chips to tonnes of chips.

The production of some fines along with the chips seems inevitable. More fines are produced when dry or rotten wood is chipped. Except for the possible irritation and the dirt they produce, the fines pose no problem. The effects of the fines can be minimized by care in design of storage and handling equipment and by wearing dust masks when the chips are being stirred up during transport processes (such as filling a bin). The large particles, on the other hand, can cause hangups in hoppers and can jam augers. It is therefore desirable to remove them. The vibrating conveyor at the processing centre does this adequately, and also removes foreign matter such as cans and rocks. Screening as part of a conveying system at

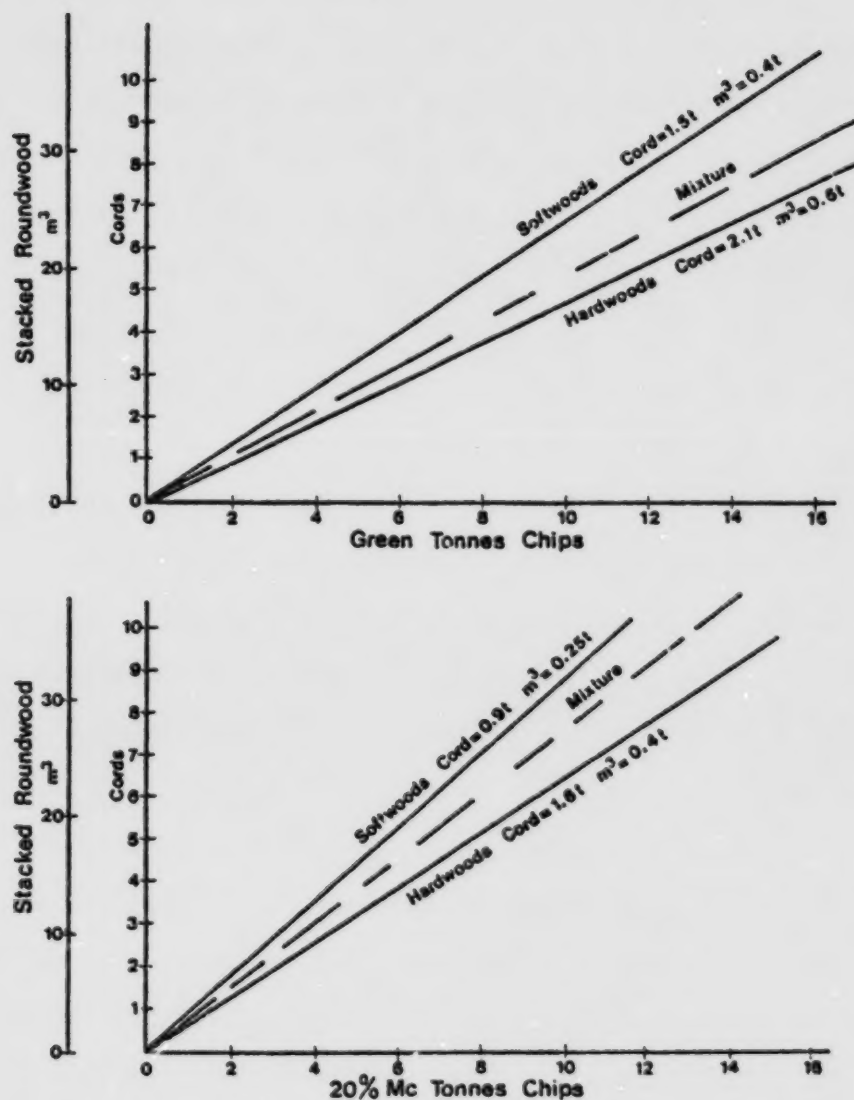


Figure 2.1. Conversions between cords and cubic meters of chips, and metric tonnes of chips. This is based upon the average values in Table 2.3.

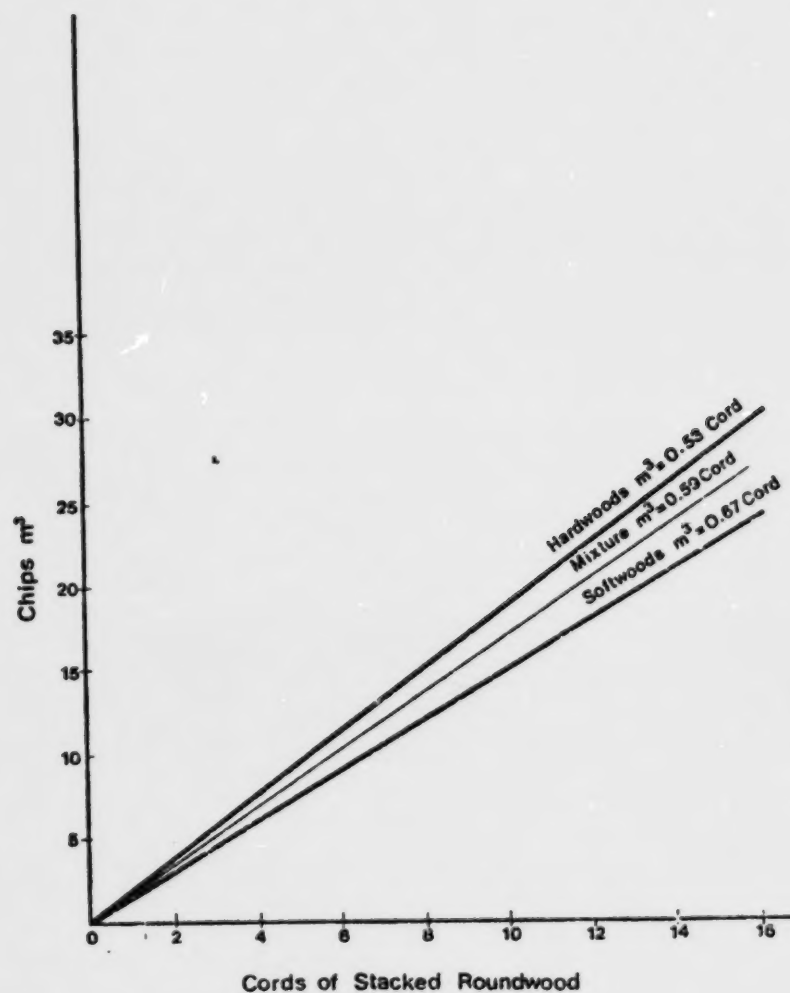


Figure 2.2. Conversions between cords of roundwood and chip volume in cubic meters. This is based upon the average values in Table 2. A cord is assumed to be 80 ft³ of solid wood in 128 ft³ of space.

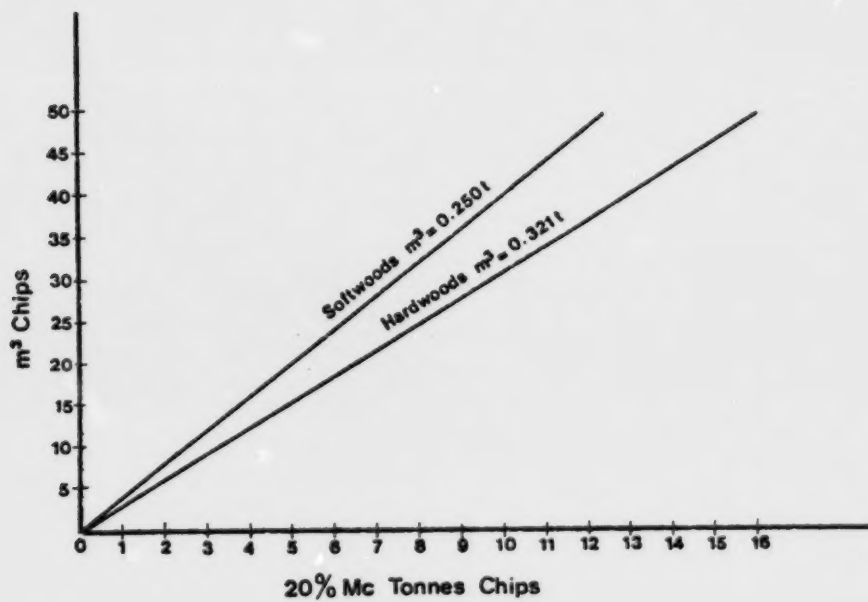


Figure 2.3. Conversions between weight (at 20% MC, dry basis) and volume of fuel chips based upon average values in Table 2.1.



Figure 2.4. Representation of volumes in m³ to make a 20% MC metric tonne of cordwood and chips. The cordwood values are from the averages in Table 2.3 and the chip values are the averages from Table 2.1.

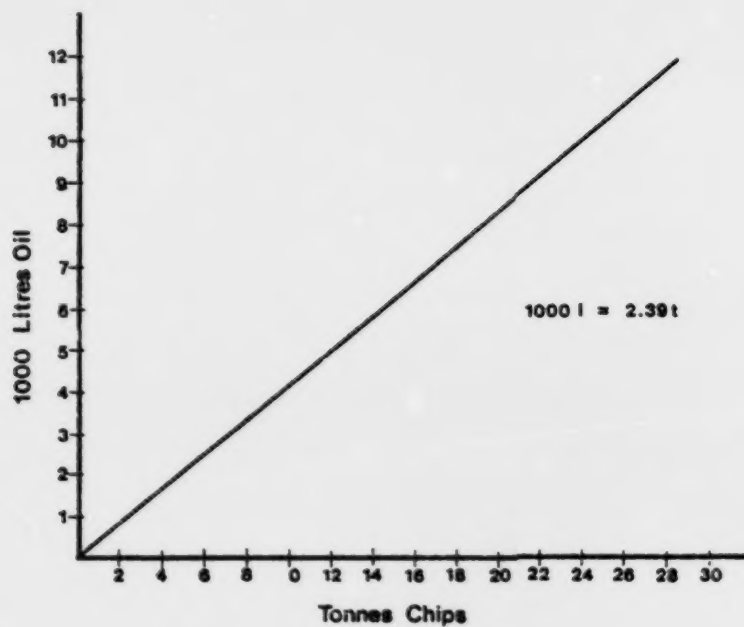


Figure 2.5. Conversions between volume of furnace oil and 20% MC metric tonnes of chips. The basis is oil at 38.8 MJ/l and the wood at 16,230 MJ/tonne (7,000 BTU/lb).

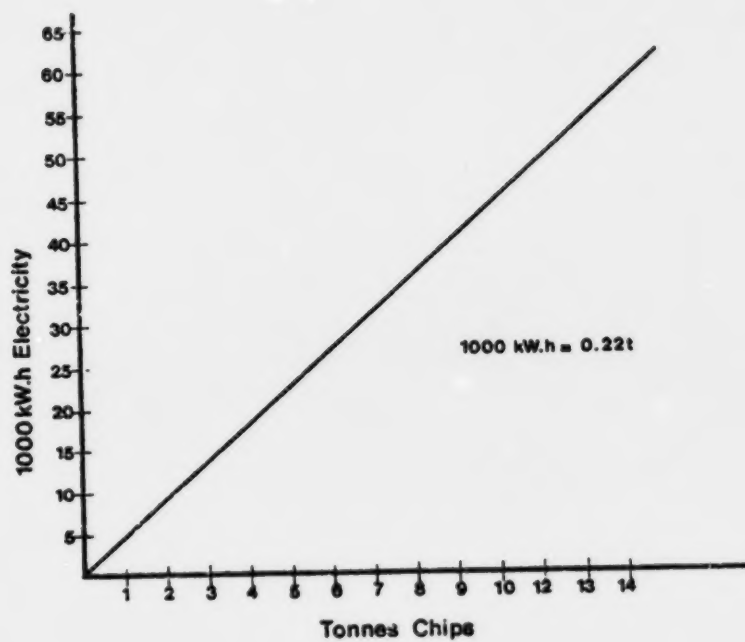


Figure 2.6. Conversion between KWH of electricity (at 3.5973 MJ/KWH) and wood (at 16,230 MJ/tonne).

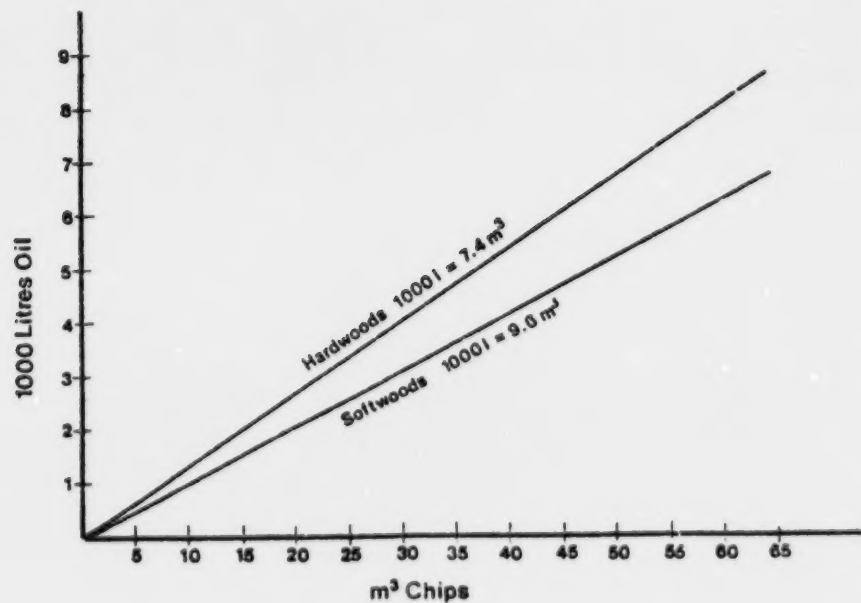
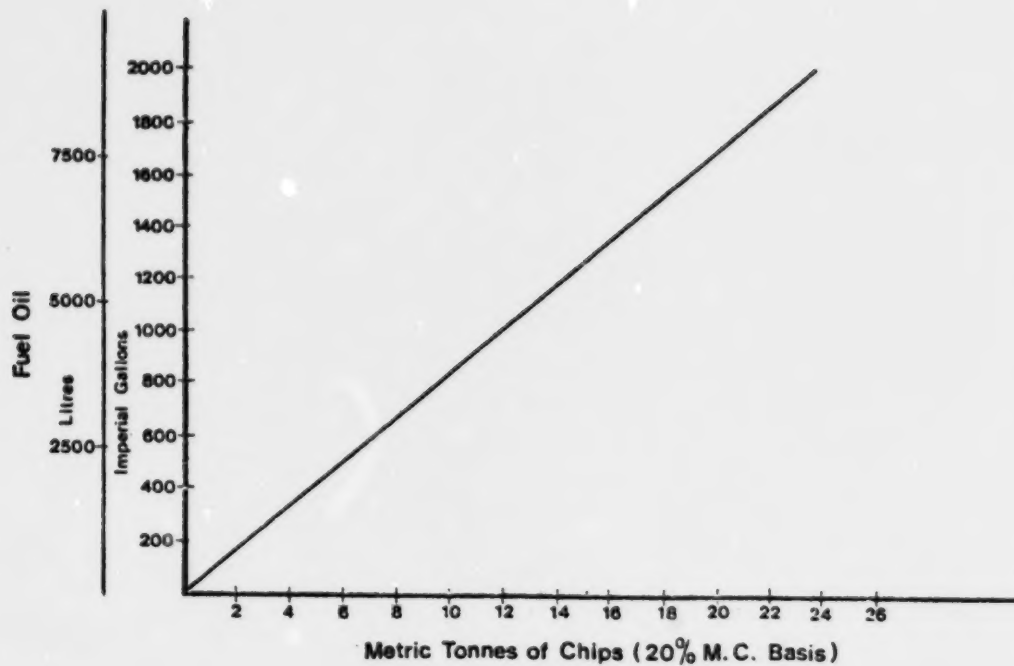


Figure 2.7. Energy-equivalent volumes of fuelwood chips (16,230 MJ/tonne, average bulk density from Table 2.1) and furnace oil (38.8 MJ/l).

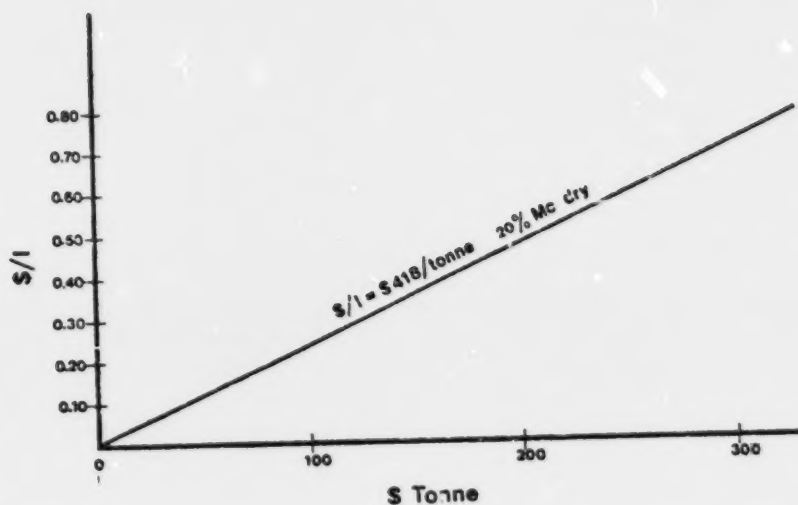


Figure 2.8. Energy-equivalent cost line (or break-even line) for oil and wood chips (based upon the relationship in Figure 2.5). For example, on a heating energy basis, oil at \$.25/l is the same value as wood at \$100/tonne. Wood available at prices less than \$100 per tonne would be cheaper than oil at \$.25/l.

a processing centre is so easy that it is recommended for all who will supply chips. Such screened chips would be a more reliable and uniform fuel.

3.0 Harvesting

3.1 Introduction

There is a dearth of information about small-scale wood chip production. None of the very limited experience worldwide or in Canada gives us a basis for estimating productivity and costs for small-scale chip harvesting operations in New Brunswick. The demonstrations reported here are an attempt to generate the needed information base.

The demonstrations were designed to use, insofar as possible, existing, low capital cost equipment and few men. The purpose was to demonstrate a scale of operation available to farmers and woodlot owners who would harvest and chip wood, either as a part-time occupation, or to supply their own needs. The only piece of equipment required, which would not be commonly available for this small scale, was the chipper. Such chippers typically process material 15 cm (6 in) or less in diameter. When powered by a farm tractor, the chipper capital cost could be low; therefore, the demonstrations used a tractor-mounted chipper and various combinations of forwarding equipment. Although crews of from two to four men operated the systems at various times, the normal crew size was three - one to operate the chipper, one to forward and one to fell and occasionally help feed the chipper.

There are several possibilities for obtaining non-merchantable wood for chipping. Slash can be gathered after a harvest of merchantable

timber, sub-standard stands can be clearcut, and thinnings can be carried out. Integrated operations on merchantable stands are also possible, although small-scale chippers may only be suitable for the smallest operations. This study demonstrated harvesting systems for slash, clearcut and thinnings. The slash harvesting and the first thinning were carried out under the sponsorship of the Energy Secretariat, Province of New Brunswick, before the Conservation and Renewable Energy Demonstration Agreement (CREDA) was developed between the Federal and Provincial governments. The remainder of the work was carried out under CREDA, which had 80% Federal and 20% Provincial funding. Because all the work is all part of the same plan, it is all integrated into this report.

3.2 Harvesting Stand and Site Descriptions

The slash pickup occurred on land clearcut the previous summer. Softwood sawlogs, studwood and pulpwood had been harvested. The slash remaining consisted of tops and branches, and some dead standing and fallen stems which were unmerchantable in the previous harvest.

There were two thinning operations. The first occurred in a stand of softwood which was interspersed with red maple stumps and shoots, and some poplar and paper birch. The manager wanted the maple removed in order to release the softwood, but he also wanted the birch left so it could mature to spoolwood standards. We removed the maple.

All of the stands that we clearcut consisted of well-stocked, small-sized hardwoods. Tree species, form and spacing made it improbable that the stands would become merchantable in their current rotation. Clearing and planting would be the fastest way to get such stands into commercial production of anything but fuelwood chips.

The second thinning was carried out in a predominantly softwood

stand where larch and small-sized material was removed in order to release the potential timber trees, as well as for aesthetic reasons.

All the stands and their designations are given in Tables 3.1 and 3.2. All were similar in slope and operability. Slope was slight and operability good. Farm tractors equipped for logging would have had little difficulty in any of them.

3.3 Harvesting, Chipping and Transport Equipment

Table 3.3 gives the combinations of equipment used to harvest the different stands. Chainsaw felling and farm tractor-powered chipping was used throughout. Both thinning operations used a skidding cone to facilitate movement of the wood bundles through the forest.

Skidding was done with conventional cable skidders, farm tractors equipped with a cable skidding winch, and, in one case, with a Yankee Yarder, (a small, portable, stationary winch). Of the three types of equipment, tractors were used most frequently and in a variety of ways. In SLASH 2, THIN 1 and CLEAR 1, the tractor remained in the periphery of the harvested area and all skidding was done with the winch. In these cases, the tractor was not equipped for moving about in the forest. A farm tractor equipped with skid pans, roll bars and protective cab was used for forwarding CLEAR 4 and 5. This tractor was taken into the stand, where material was winched to it. Then the tractor skidded the material to the chipper. In CLEAR 1, only one farm tractor was used. It was alternately coupled to the winch and the chipper.

Table 3.1. Detailed description of stands harvested and chipped for fuel (using small-scale equipment).

Date	Designation	Location	Area/ hectares	Average Stem Diam. cm	Average Stems/hectare	Estimated OD tonnes/ ¹ hectare
1980	SLASH 1	Private Woodlot	0.7	-	-	34.7 ³
1980	SLASH 2	Private Woodlot	0.4	-	-	17.4 ³
1981	THIN 1	UNB Woodlot	0.8	5.6 ²	9435 ²	87.5 ²
1982	CLEAR 1	CFB Gagetown	0.2	9.2	5800	84.3
1982	CLEAR 2	CFB Gagetown	0.2	7.0	4200	115.7
1982	CLEAR 3	CFB Gagetown	0.2	7.2	7800	138.7
1982	CLEAR 4	UNB Woodlot	0.2	7.2	5400	101.2
1982	CLEAR 5	UNB Woodlot	0.2	6.9	3600	105.2
1983	THIN 2	UNB Campus	1.8	13.9 ²	3839 ²	241.7 ²

¹ Developed using Ker's (1980) biomass equations.

² Average for stand, but not material harvested.

³ Line intersect method of estimating slash (VanWagner 1968)

Table 3.2 Detailed description of stands harvested and chipped for fuel (using small-scale equipment).

Date	Designation	Species mix, % by weight ¹						Harvesting
1980	SLASH 1	b. fir 80	spruce 18	pine 2				softwood slash
1980	SLASH 2	b. fir 80	spruce 18	pine 2				softwood slash
1981	THIN 1	r. maple 50	fir 34	w. birch 10	poplar 4.6	spruce 1		red maple thinnings
1982	CLEAR 1	poplar 49.3	r. maple 28.8	w. birch 20.6	b. fir 1.3			hardwood clearcut
1982	CLEAR 2	w. birch 62.7	poplar 23.0	b. fir 12.2	r. maple 2.0			hardwood clearcut
1982	CLEAR 3	poplar 31.5	r. maple 29.5	w. birch 29.3	spruce 9.3	b. fir 0.4		hardwood clearcut
1982	CLEAR 4	beech 74.8	b. fir 22.2	spruce 2.4	r. maple 0.6			hardwood clearcut
1982	CLEAR 5	beech 99.1	b. fir 0.7	spruce 0.2				hardwood clearcut
1983	THIN 2	larch 52.0	b. fir ² 26.2	w. pine 9.9	spruce 5.7	r. maple 4.5	cedar 1.1	softwood thinning

¹Developed using Ker's (1980) biomass equations.

²15% alive, 10.3% dead (of total species mix)

Table 3.3. Machines used to forward material to farm tractor-mounted fuelwood chipper, and to move chips to storage.

Designation	Forwarding	Chip Transport
SLASH 1	Can Car Tree Farmer C5D 100 hp cable skidder	Farm tractor and trailer, 1/2 ton truck and trailer.
SLASH 2	MF 135 35 hp farm tractor with Farmi JL 30 logging winch	Same as SLASH 2
THIN 1	Same as SLASH 2	3-ton dump truck
CLEAR 1	John Deere 2130 69 pto hp farm tractor with Farmi JL 30 logging winch (same tractor used to power chippers)	Roll-on, roll-off container, either 85 or 113 cu. m.
CLEAR 2	Can Car C4D 80 hp cable skidder	Same as CLEAR 1
CLEAR 3	Same as CLEAR 2	Same as CLEAR 1
CLEAR 4	MF 135 35 hp farm tractor with Farmi JL 30 logging winch	Same as CLEAR 1
CLEAR 5	Same as CLEAR 4	Same as CLEAR 1
THIN 2	Yankee Yarder 5 hp stationary cable skidder	Same as CLEAR 1

Felling was accomplished with chainsaws in all cases, and chipping with either a Bruks 720 or Arvin disc chipper mounted on a Massey-Ferguson 165 farm tractor or a John Deere 2130 farm tractor.

3.4 Harvesting Personnel

SLASH 1 and 2 and THIN 1 were contracted with a small company incorporated to do work in woodlots. The crews consisted of a minimum three men, but frequently four or five men were employed. The foreman coordinated data-taking, and each man kept his own time. The president of the company, who also acted as working foreman, became a graduate student at the Faculty of Forestry, majoring in small-scale chip production. That person, Graham Savage, worked as an employee of the project for the clearcutting operations in the summer of 1982 (CLEAR 1 to 5). He acted as working foreman and data-collection coordinator for the three-man crew, including himself. All workers, with the exception of the skidder operator on CLEAR 2 and 3, were Forestry or Forest Engineering students or recent graduates. All except one (the Forest Engineer) had extensive woods experience and seemed as capable as any woodworker. The Forest Engineer learned quickly and soon became as competent as the more experienced among the crew. During the clearcutting, the skidder operator added a fourth man to the crew (CLEAR 2 and 3).

THIN 2 was an operation contracted with the University by another small woodlot improvement company. The chip project agreed to supply the crew with a tractor and chipper and to bear the cost of transporting the chips to the project processing centre on the Royal Road. We hired a man to be present and take data throughout the operation. The chips and the data became the property of the project. Experienced Forestry student woodworkers manned the THIN 2 project as well. The crew initially consisted of four men, but dropped back to three after a few days. The company manager assisted with the labour from time to time.

3.5 Data Acquisition

Each crew member, or someone assigned to take data, recorded all productive and non-productive working time, noting its particular nature and designation. Where possible, operating hours for the various machines were recorded and fuel use of all machines was also measured and recorded.

In SLASH 1 and 2 and THIN 1, chip production was measured on a load-by-load basis, using the load volume and samples of chip bulk density and moisture content. In all other operations, each load was weighed, in addition to recording its volume. Extensive moisture content sampling was carried out on a continuing basis.

3.6 Production Per Man and Machine-Hour

3.6.1 Results

Average percentages of man-hours required to harvest fuel chips from the various stands are given in Figure 3.1. These are broken down in Table 3.5. Also given in Table 3.5 are the percentages of productive machine-hours to produce chips. The data from which these percentages were derived is shown in Table 3.4.

3.6.2 Discussion

Generally speaking, the harvesting process consists of felling, forwarding and chipping. In slash harvesting, however, there is no felling and, therefore, man-hour comparisons with the other two methods are difficult over the whole harvesting process. A more accurate man-hour comparison can be made between the 3 methods on the basis of forwarding and chipping only, as is done in Table 3b. Ratios given are developed from Table 3.4.

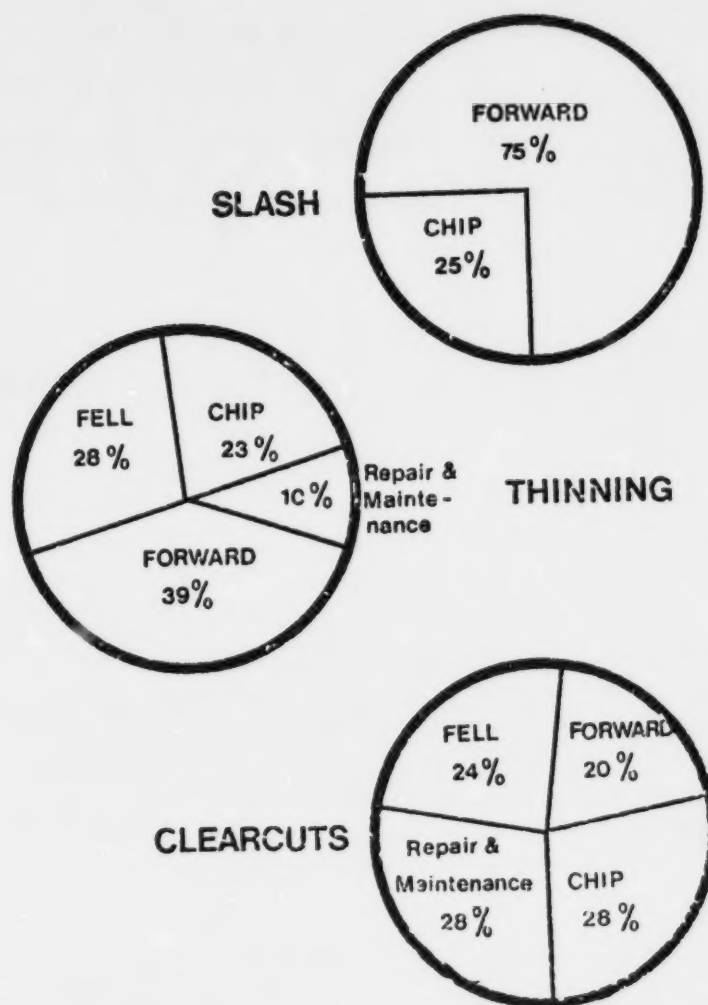


Figure 3.1. Relative amounts of man-hours to produce a metric tonne (20% MC) of chips for the three types of material harvested in the small-scale demonstrations. The SLASH represents a single operation, THINNINGS the average of two operations and CLEARCUTS the average of 5 operations. Data from which the figure was drawn were taken from Table 3.4. The percentages are broken down in Table 3.5.



Figure 3.2 Bucking slash hauled in with the farm tractor-mounted winch.



Figure 3.3 An example setting of four-wheeled drive rubber-tired skidder chokers on slash in the SLASH operations.

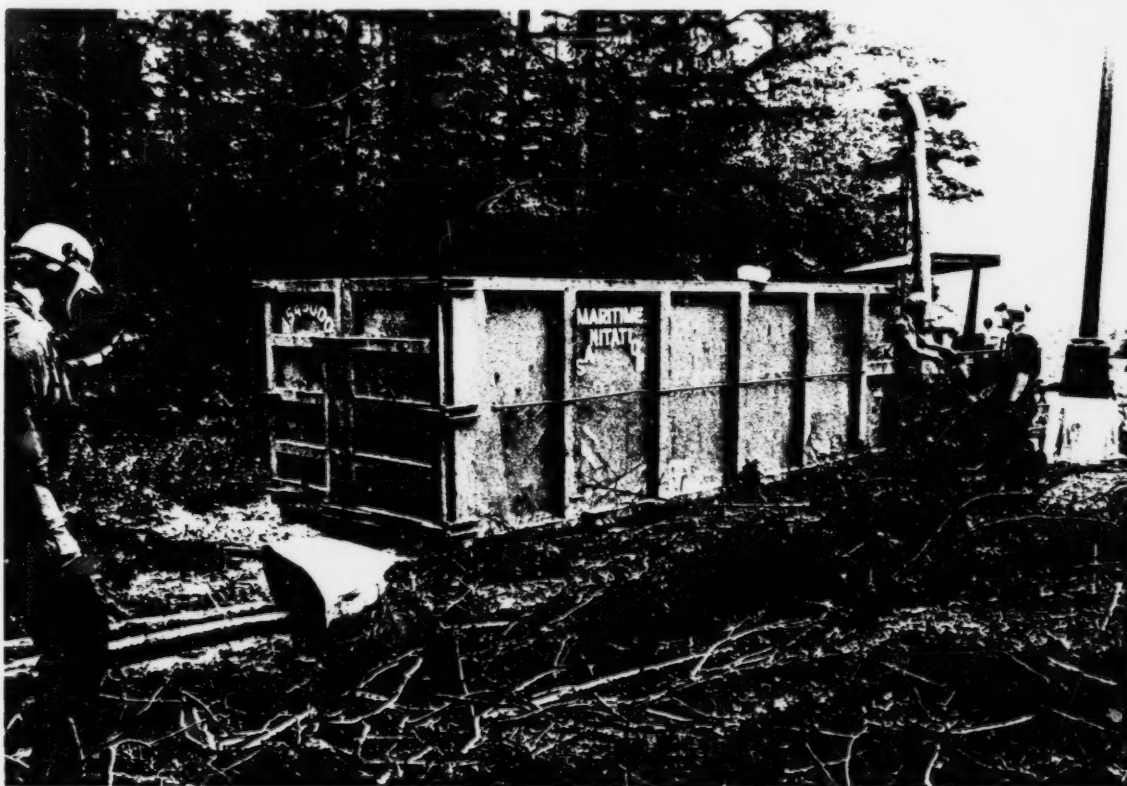


Figure 3.4 Another chipper and container setup in a THIN operation. Wood skidded by small winch is entering photo inside skidding cone. Winch operator is standing just in front of chipper to right of container.

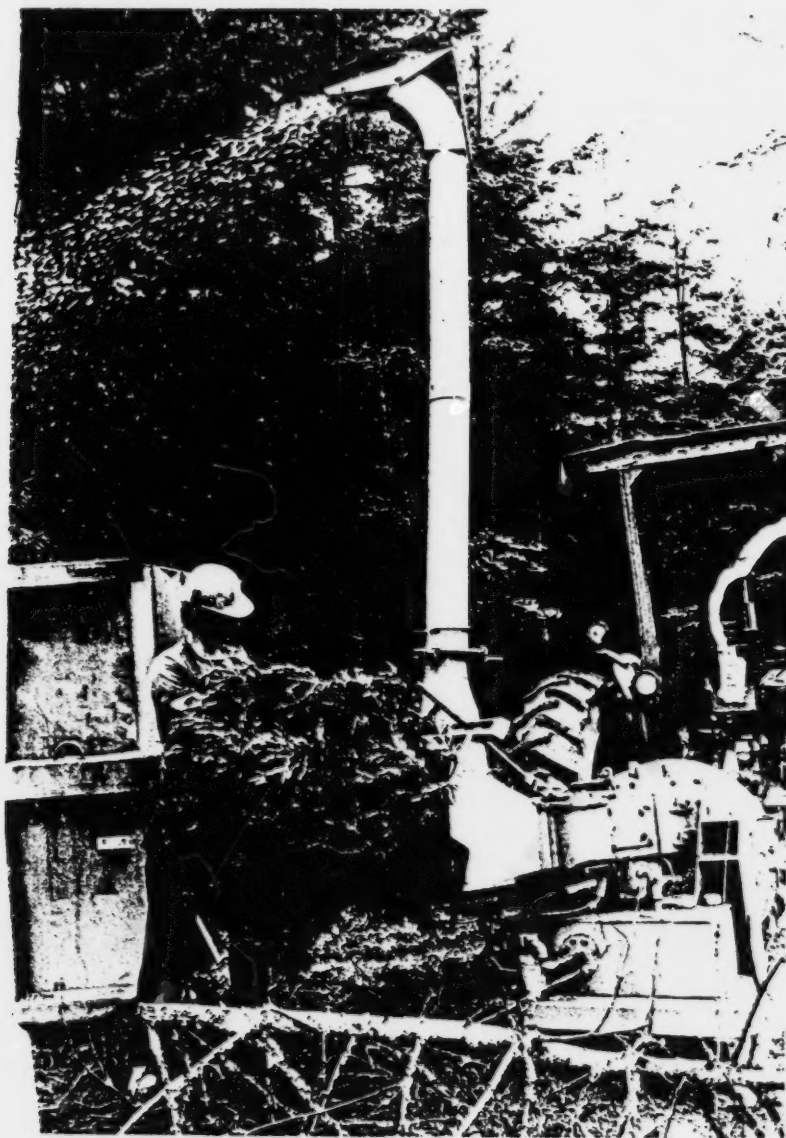


Figure 3. 5 Feeding the Arvin chipper with limbs removed in the delimbing of larger stems such as in Figure 3.27. A THIN operation.



Figure 3.6 Skidding with the farm tractor in a clear operation.

Table 3.4. Man and machine-hours per 20% MC tonne of chips produced.

Designation	Man - hr./tonne					Productive machine-hr./tonne		
	Fell	Forward	Chip	Repair and Maintenance	Total	Forward	Chip	Total
SLASH 1	-	6.9	2.3	NA ¹	9.2	2.3	0.9	3.2
SLASH 2 ²	-	11.2	NA ³	NA ¹	-	5.5	NA ³	-
THIN 1	4.3	7.7	4.4	NA ¹	16.4	2.6	1.5	4.1
CLEAR 1	2.2	2.2	3.6	2.4	10.3	NA	NA ¹	2.0
CLEAR 2	1.3	1.6	1.3	0.9	5.1	1.2 ⁴	1.2 ⁴	2.4
CLEAR 3	2.3	1.7	3.2	1.9	9.0	1.6 ³	1.2	2.8
CLEAR 4	3.6	2.5	3.3	2.5 ⁵	11.9	1.6	1.8	3.4
CLEAR 5	1.4	1.2	1.2	2.1	5.9	1.0	1.0	2.0
THIN 2	4.5	4.4	2.8	1.6	13.3	4.4	1.7	6.1

¹ Not recorded separately

² Assuming same chip production relationship to initial inventory assessment as SLASH 1

³ Not chipped

⁴ Scheduled, not productive

⁵ Adjusted to mean of other 4 because of unusual maintenance and repair requirements

Table 3.5. Percentages of man-hours spent in various activities to produce fuel chips using small harvesting systems.

Designation	Man-Hours			Repair and Maintenance	Productive Machine-hrs.	
	Fell	Man-Hours Forward	Chip		Forward	Chip
SLASH 1	-	75	25	NA	72	28
THIN 1	26	47	27	NA	63	37
CLEAR 1	21	21	35	23	NA	NA
2	25	32	26	17	NA	NA
3	25	19	35	21	NA	NA
4	30	21	28	21	47	53
5	24	20	20	36	50	50
THIN 2	34	33	21	12	72	28

Table 3.6. Comparisons of man-hours to forward and chip for three harvesting methods.

Method	Ratio			
	Man-Hrs.		Prod. Machine-Hrs.	
	Forward:	Chip	Forward:	Chip
Slash pickup	3	1	2.6	1
Thinning	1.6	1	2.2	1
Clearcutting	0.8	1	1	1

In both slash pickup and thinning, more man-hours were spent forwarding than chipping, while chipping accounted for more man-hours than forwarding when the clearcutting method was used. As expected, the same trend occurs with productive machine-hours. Disregarding differences in method, this analysis shows that clearcutting makes best use of man and machines, with thinnings less productive and slash pickup the least productive. Considered from another viewpoint, slash pickup and thinning do generate more employment. Also, the ratios suggest that small chippers such as the one used by the project have more flexibility for thinning and slash salvage operations because they generate more work in the forest than during clearcutting.

Felling required a somewhat greater proportion of labour time in thinnings than in clearcuts. This is expected because of the selection necessary in a thinning. Forwarding also required a substantially greater proportion of man-hours in the thinnings than in the clearcut because more manhandling is required to ready the smaller stems of the thinnings for skidding.

Repair and maintenance used a high percentage of labour time in

the clearcutting. This was caused by a combination of unfamiliarity with the equipment and loan or rental of some of the equipment. The loaned equipment, in particular, had not had the care and preventive maintenance normally provided owner-operated equipment.

Table 3.4 gives man and machine-hours required to produce a tonne of chips for the various operations and for functions within each operation. Table 3.5 shows percentages based upon the values of Table 3.4. Thinnings required the highest input of man and machine-hours because of the need for more manual handling both in forwarding and chipping. Slash pickup required slightly fewer man-hours, probably because no felling was required. There is wide variability within the clearcutting operations, with man-hours per tonne ranging from about 5 to 12. Those with the greatest overall requirement generally used more time throughout all phases of the operation, rather than in certain categories. In operations like these, where a sequence of events occurs, a slowdown in one function can slow the others. In the recording of data for the project, such a slowdown in any function which depends upon another would not be recorded as delay time unless a breakdown had occurred; it simply would take more time to do the job. This is probably the explanation for the variability. Neither stand conditions nor equipment used seems to relate to the variability in the clearcutting results.

On the average, over all the operations, 2.8 man-hours and 1.3 machine-hours were required to chip a tonne of chips (20% MC basis). Proper matching of men and chipper would thus call for two men feeding. In general, the chipper produced just over 0.7 tonne per hour (production was actually 0.77 tonne/hr.) suggesting that about two working days (13 hours) would be required for two men to chip a year's supply of 10 tonnes to heat a home.

Times spent felling and forwarding were more variable in the operations demonstrated. The rate produced by the system of machines was from 0.2 to 0.5 tonnes per hour, while the men produced from 0.06 to 0.2 tonnes per hour. If the manpower were increased to match the equipment capability, it would, therefore, take from somewhat more than a work week (6.25 days) to just about a month (4.2 weeks) for one man to produce the annual requirement for a home. The least time-efficient operation was THIN 1, while clearcutting represented the most efficient use of time.

There is not much difference among the man or machine-hours needed to forward a tonne of chips within the clearcutting operations, even though machines of different capabilities were used for different operations. This suggests that some other component of the system was providing the bottle-neck which restricted the utilization of the higher-capacity machine. During the work, the skidder did spend time waiting for the chipper to clear its drop area. Because they could not be moved by the harvesting crew, the chip bins were restricted to a single landing adjacent to the chipper. The amount of material at the landing was necessarily small because large piles are difficult to manually unscramble. Also, if they became large enough to spread some distance from the chipper, manual dragging was needed. Balancing the logging system is essential to obtain optimum machine and man utilization.

In THIN 2, a smaller, simpler machine was used for skidding. Its lower capacity resulted in higher machine-hours to forward a tonne. A trade-off was made, one which any operator might consider. It is interesting to note that the THIN 2 operation came fairly close to the man-hour productivity of the poorest clearcut. A similar, but larger, capacity yarder might have put this thinning operation into the same productivity category

as the clearcuts, on both a man and machine-hour basis.

3.7 Energy Used in Harvesting and Transportation

3.7.1 Results

Table 3.7 shows the energy used to harvest, chip and transport the chips to the processing centre. The ratio of that total energy to the lower heating value of the chips is also given. Table 3.8 gives the harvesting breakdown of energy use and the ratio of energy produced to energy consumed. The ratios for the harvesting phase ranged from 13:1 for slash pickup to 47:1 for clearcutting. Transportation reduced the ratios according to the distance carried.

3.7.2 Discussion

There is a correspondence between man and machine-hours (Table 3.4) and energy used per tonne of chips (Table 3.8). Either in total or in part, those operations using more hours also used more fuel. This is not surprising, since operating machines have a certain basic fuel requirement, even when they are not producing. An exception occurred when the basic type of machine was changed. The simple forwarder in THIN 2 required more labour and operating time per unit of production but had a low fuel consumption.

Table 3.9 shows that chipping is the major consumer of harvesting energy, with forwarding second. Again, when the simple forwarder was used for thinning (THIN 2), forwarding consumed a dramatically smaller portion of the total energy.

For short hauls, energy consumed by transport is a small proportion of total energy investment in the chips (Table 3.10). With greater hauling distances the proportion increases to the point where, in the examples from this study, a 100 km (62 mi) haul would consume about the same

energy as the chips contained. The approximate relationship between hauling distance and percentage energy used for hauling in this demonstration was:

$$\% \text{ of total energy to transport} = 0.92 \times \text{km}$$

This particular relationship is applicable only to the conditions and equipment we used; nonetheless, some similar relationship could be developed for each case to be considered.

3.8 Comparisons of Biomass Estimates and Chips Harvested

3.8.1 Results

The estimates of biomass present and the actual weights removed as chips are given in Table 3.11. Biomass equations are designed to estimate total above-ground biomass. Such equations are in early stages of development, but are the only estimating method currently available. Because some material is left behind in most chipping operations, accurate estimates of biomass would underestimate weight of chips. In our experience, the biomass equations generally did underestimate. In the two thinning cases, a high proportion of material cut went through the chipper because most of the material was small enough for the chipper and because the objective was to leave the stand as clean as possible.

3.8.2 Discussion

There is considerable variability in the percent of material actually produced and the amount estimated from the cruises. For clear-cut operations similar to those demonstrated, it would appear that estimates based upon total biomass equations are about twice that which can be produced as chips. Estimates that are halved would appear to give some idea of actual production possibilities. For thinnings, the case is less clear; in THIN 1, the amount produced came very close to the amount estimated, while THIN 2 produced one-third less than predicted. Both the explanation for the

Table 3.7. Comparisons of chip harvest and transport energy (in MJ) to potential combustion energy².

Designation	Harvest (including chipping)	Transport	Total	Energy In Chips ²	Energy Produced/ Energy Used
SLASH 1	16,105	350 ³	16,455	211,640	13:0
CLEAR 1	5,426	2,785 ⁴	8,211	217,969	26:5
2	4,877	2,785 ⁴	7,672	221,702	28:9
3	5,307	2,785 ⁴	8,092	163,436	20:2
4	9,867	866 ⁵	10,733	224,299	20:9
5	5,303	866 ⁵	6,169	249,455	40:4
THIN 2	12,206	1,031 ⁶	13,237	551,820	41:7

¹ Gasoline at 34.00 MJ/l and diesel oil at 40.76 MJ/l

² At 16,230 MJ/20% MC tonne (7,000 BTU/lb)

³ 1 km

⁴ 60 km

⁵ 18 km

⁶ 8 km

Table 3.8. Energy per 20% MC time (in MJ) used in machines which produced fuelwood chips.

Designation	Fell	Forward	Chip	Buck	Harvesting Energy Produced ⁶ / Total	Energy used
SLASH 1	NA ²	517	718	NA ³	1235	13:1
	NA ²	819	NA ⁴	NA ³	-	-
CLEAR 1	56	106	242	NA ³	404	40:1
2	27	130	133	67	357	45:5
3	64	101	298	64	527	30:8
4	80	266	318	50	714	22:7
5	53	109	163	20	345	47:0
THIN 2	20	27	312	NA ⁵	359	45:3

¹Gasoline = 34.00 MJ/l; diesel oil = 40.76 MJ/l

²Little felling

³Not recorded separately

⁴Not chipped

⁵Little bucking

⁶At 16,230 MJ/20% MC tonne (7,000 BTU/lb)

Table 3.9. Percentages of energy consumed in various phases of chip production.

Designation	Fell	Forward	Buck	Chip
SLASH 1	-	42	-	58
CLEAR 1	14	26	NA ¹	60
2	8	36	19	37
3	12	19	12	57
4	11	37	7	45
5	15	32	6	47
THIN 2	6	8	-	87

¹ Not recorded separately.

Table 3.10. Percentages of energy used to harvest and transport chips.

Designation	Harvest	Transport	Transport Distance, km
SLASH 1	98	2	1
CLEAR 1	66	54	60
	64	56	60
	66	54	60
	92	8	18
	86	12	18
THIN 1	92	8	8

Table 3.11. Comparisons of chips produced to total biomass estimates.

Designation	Chips Produced			Estimated	% Estimate of recovered
	Green tonnes/ hectare	MC	OD tonnes/ hectare	OD tonnes/ hectare	
SLASH 1	15.5	45 ¹	10.9	34.7	31
SLASH 2	NA ²	NA ²	NA ²	17.4	NA
THIN 1	22.4	44 ³	15.6	14.5 ⁴	107
CLEAR 1	106.9	91	56.0	84.3	66
2	84.3	88	56.9	115.7	49
3	88.4	87	42.0	138.7	30
4	102.9	78	57.6	101.2	56
5	116.0	81	64.0	105.2	61
THIN 2	27.2	44	18.9	28.1	67

¹Year-old slash

²Not chipped

³Sour felled

⁴Only thinnings considered using before and after harvest sampling

variabilities and the methods of improving the estimates should be pursued because more accurate estimates could be helpful to a potential operator, especially for operations marginal in cost effectiveness.

3.9 Transport of Chips to Storage

The cost of chip transport is influenced by distance and vehicle type. We searched the local area for vehicles suitable for transporting chips, and determined cost for each. The cost was calculated using a simple simulation model which showed the relationship between chip unit transportation cost (\$/tonne) and one-way transportation distance. The vehicle types analyzed are common to most localities.

A comparison of results is given in Figure 3.9.1. The chip van is the least costly way to transport chips, with the small utility trailer the most expensive. The cost is very sensitive to load size, explaining why vehicle road capacity is so important when transporting bulky fuels. Cost is also dependent upon charging method, as the example in Figure 3.9.2 shows.

Although chip vans were the least expensive option, they require costly unloading to accomplish reasonable unloading times. The next best option was the roll-on, roll-off (Ro-Ro) container used by waste disposal companies. These containers are dumped quickly by the truck which carries them. They are also virtually undamageable, which can be an important consideration in remote locations. Therefore, the Ro-Ro container system was chosen for the project.

Trucking can be hired by distance or hourly rate. When using detachable load carriers, numbers of carriers can influence trucking costs. Some examples are shown in Figure 3.9.2.

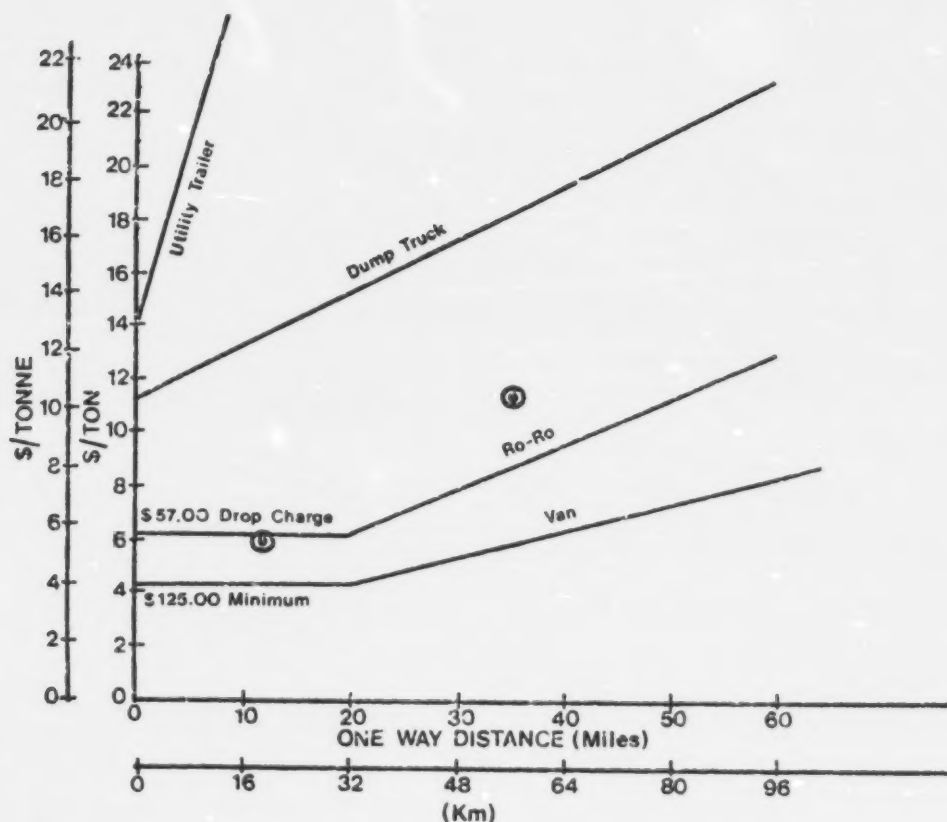


Figure 3.9.1. Expected costs of transporting chips using several vehicle types. Two vehicles would be required to maintain continuous chip production in each case. Assumptions used in every case were a speed of 65 KPH (40 MPH), and a loading (chipping) rate of 2.8 m³/h (100 ft³/h). Other assumptions are:

	V.T.	D.T.	R.R.	YAN
Vehicle Load Volume	4.2 m ³ (150 ft ³)	21.7 m ³ (770 ft ³)	26.7 m ³ (945 ft ³)	83 m ³ (2933 ft ³)
Unloading Rate	70 m ³ /h (2480 ft ³ /h)	130 m ³ /h (4608 ft ³ /h)	161 m ³ /h (5670 ft ³ /h)	17 m ³ /h* (600 ft ³ /h)
Hourly Machine Charge	\$20	\$30	\$51	\$57

* Mechanically-assisted manual unloading.

The two circled points show project experience using the Ro-Ro containers. The smaller distance was the UND Woodlot and the longer CFB Gagetown.

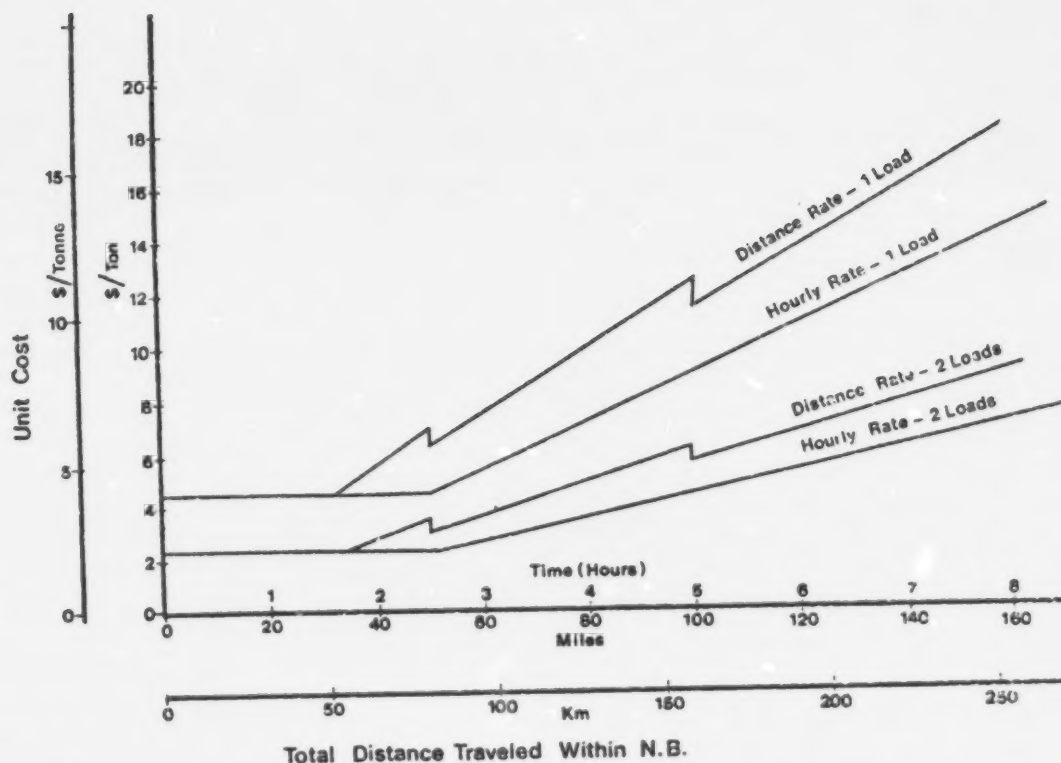


Figure 3.9.2. Estimated costs (based upon quotes made in February, 1982) of transporting chips by van charged either by the hour or by the mile. A single tractor was assumed, but with either one van (1 load) or two vans (2 loads). In the 1 load system, the tractor would drop a van to be filled, and then go back later to pick it up, unload it, and return it. With 2 vans the tractor would arrive at the chipping site with an empty van in tow each time, thereby decreasing tractor time and mileage. There was a \$125 minimum charge in each case illustrated, and the van held 83m³ (2,933 ft³) of chips which weighed 25 tonnes (28 tons).

4.0 Storage, Screening and Drying

4.1 Storage and Drying in Collapsible Bin

4.1.1 Introduction

A method of chip storage which could be moved about, even to the site of chipping, and which could also provide some drying, would be useful in some chip supply situations. At one point in the project, more chips were being produced than could be accommodated in the available storage capacity. This situation was used to test a simple, portable bin. The bin chosen is a type used for surplus grain, in keeping with the policy of trying to adapt existing technology and hardware to chip production, drying, storage and delivery.

4.1.2 Collapsible Bin Description

The bin consists of two pieces of strong woven polymer. One piece is the base and the other is the cover. The base is similar to an above-ground swimming pool. When set up, it encloses a circular (or, more accurately, cylindrical) space 7.6 m (25 ft) in diameter and 1.5 m (5 ft) high. It is supported on the outside by a circle of wire mesh. The cylinder is filled with chips to the top of the wire mesh, and above that, the chips are mounded to a cone. The top, which is cut to cover the cone-shaped mound and overhang the side of the cylinder, is then put in place, protecting the contents from the weather. Since the bin was to be loaded with green chips, we added a drying mechanism which consisted of a spiral of 15 cm (6 in) diameter perforated, flexible, plastic drain pipe placed in the bin bottom. The inside end of the pipe was closed with a plug and the outer

end was connected to a section of 15 cm (6 in) Sonotube (solid-walled, wax-impregnated cardboard tubing) sufficiently long to extend through the top of the pile. After loading the chips, a 30 cm (12 in) diameter fan directly mounted on the shaft of a 1/12 hp electric motor, was added to the top of the tube. This fan is in a metal housing and is normally used with a perforated metal pipe to dry "hot spots" in grain bins. The fan pulled air from the Sonotube and perforated plastic pipe, thereby moving it down through the chips.

The bin is designed to hold 88m³ (2,500 bu.) of grain. This is a volume equivalent to about 12 (softwood) to 18 (hardwood) tonnes of 20% MC chips. Such a bin would, therefore, hold more than a year's supply of fuel for a typical house.

4.1.3 Collapsible Bin Cost

The total cost of the bin, including drying apparatus, was approximately \$1,160. Details are given in Table 4.1.

Table 4.1. Cost of collapsible bin and associated apparatus for drying wood chips.

<u>Item</u>	<u>Cost</u>	
Bin:		
2500 bu Quik Bin	\$909.06	
Provincial Sales Tax	72.72	
Total		\$981.78
Drying Apparatus:		
1 1/2 hp fan	55.00	
31 m of 15 cm perforated pipe (Big O)	108.00	
15 cm Sonotube and screw clamps	15.72	
Total		178.72
Total For installation		\$1,160.50

4.1.4 Collapsible Bin Results

The bin was loaded with chips, using a dump tractor trailer. Considerable manual shovelling was required because the truck could not place the chips in the centre of the bin; it could only slide them into one side. Two other satisfactory methods of loading such a bin would be to use a conveyor or to chip directly into the bin.

Loading occurred in mid-summer, and the fan was operated until early fall. Chip MC was sampled at various points in the pile during the drying period. Drying proceeded from the top down, but was somewhat uneven. There were areas of apparent low air flow, particularly around the bin periphery. Wet chips with considerable fungal growth were found there. The fungi which grew were wood decay types, and not the potentially pathogenic thermophilic species. This suggests that even in areas with not enough air flow for good drying there was enough flow to prevent heating of the chips.

The bin was unloaded throughout the winter as required. The gradual unloading destroyed the conical top, allowing water pockets to develop in the bin roof. This caused leaks at seams in the material, wetting chips under the leaks and resulting in water build-up in the bin bottom. Such a bin works best when filled and unloaded in single operations.

Unloading was accomplished using either a shovel or a grain auger. The auger method was only partly mechanical because it required manual scraping of chips into the inlet. Removing snow from the bin top required as much manual labor as chip removal.

The use of proper loading and unloading equipment would minimize damage to the bin, extending its life expectancy to several years, and thus improving its cost effectiveness.

4.1.5 Conclusions

The Quik Bin did provide emergency drying and storage of fuel wood chips sufficient to heat a home. Loading and unloading of chips were difficult, however, and cost effectiveness would be questionable unless several years of service were possible. It seems that this grain storage device is not as easily adaptable to wood chips as had been hoped. Probably a simple, rigid structure would have functioned better with wood chips since chips do not flow as well as grain and are not normally unloaded all at once. A simple space frame or pneumatically-inflated structure should also be investigated for this purpose.

4.2 Home Storage Bins

4.2.1 Introduction

Each chip-heated building will need some fuel storage on the premises. Even with frequent and regular delivery, some fuel should be on hand to continue heat in the event of interruptions in delivery. Most homes should be able to accommodate on-premises storage of sufficient chips for several weeks because too-frequent deliveries are an inconvenience. A bin sufficient for a year's supply of about 10 tonnes (35 m³) would probably be ideal, but physical limitations on many premises would prevent a bin of this size.

Any bin should be located as near to the furnace as safety allows. This minimizes chip handling effort.

4.2.2 In-Ground bin Considerations

Proximity to the furnace was one main consideration in planning the in-ground bin. Another was aesthetics; an above-ground bin would be unsightly and would obstruct house windows if it were in proper proximity to

the furnace. A bin submerged in the ground just outside the basement wall adjacent to the furnace met both placement and aesthetic criteria, but the location imposed another limitation; underground services, shrubs, a walk, and a driveway limited the size of the bin. This size and location might be suitable for many suburban and even urban homes, which may not have space for a whole year's supply.

4.2.3 In-Ground Bin Description

In constructing the bin, pressure-treated wood was chosen over masonry materials bin because of its ease of erection. A design for preserved wood foundations was used. Its design is shown in Figures 4.2.1 and 4.2.2.

One of the plywood roof panels is removable for filling the bin. The chips can be bagged and thrown down through the opening, or the bin can be bulk-filled quickly using many types of vehicles, but it is particularly suited to a dump truck. The bin is diagrammed in Figures 4.2.1 and 4.2.2.

4.2.4 In-Ground Bin Cost

Total bin cost, including labour, insulation and interior sheathing, was approximately \$1,500. In an installation where insulation was not needed, the bin cost would have been about \$1,200. Should the owner provide his own labour, the total materials cost (uninsulated) would have been \$875.

4.2.5 In-Ground Bin Results

The bin has been used for one heating season. It was loaded a few times from a utility trailer, scraping the chips from the trailer by hand. The work was easy. Regular deliveries were provided by a 3-ton truck with dumping body. The body was raised, allowing the chips to slide into the bin. Some hand guidance was necessary to help the chips into the bin, and some spreading was necessary in the bin as loading progressed. One

truckload completely filled the bin, and two persons accomplished the loading in 10 to 20 minutes. The bin holds about 13 m³ (480 ft³), or about enough for one-third of a heating season for the house if dry hardwood chips are used. For last year's heating season (the first for the bin), moist softwood chips were used. This necessitated more frequent bin filling and therefore, provided more experience with the bin.

The stoker hopper is just inside the basement wall adjacent to the bin, making loading easy. So far, grain scoops or pails have been used to load the stoker hopper. With screened chips, loading took about 10 minutes daily. Use of some small conveyor to fill the hopper is possible, and may be considered for the future.

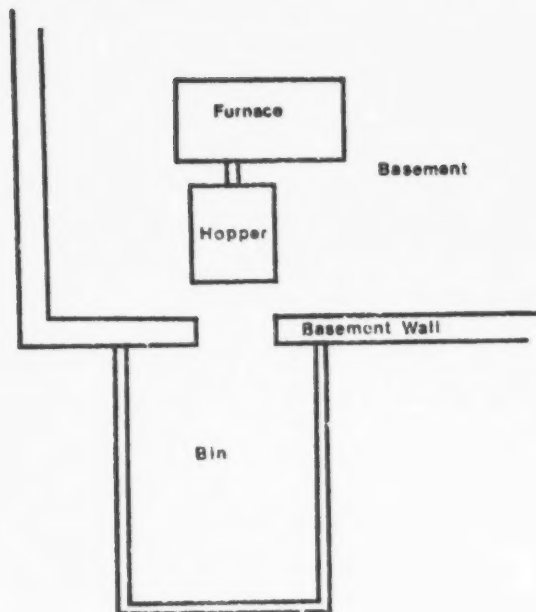


Figure 4.2.1. Plan view of the in-ground home storage bin, basement and stoker-furnace combination.

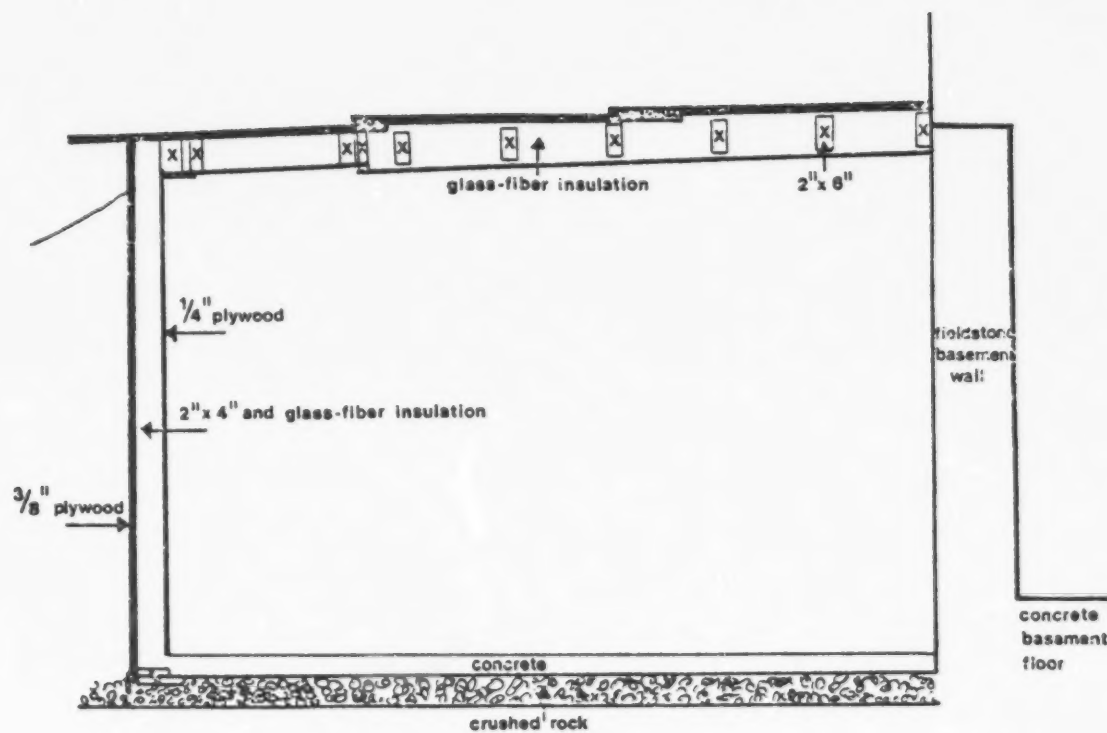


Figure 4.2.2. Longitudinal section view of the in-ground home storage bin.

4.2.6 Above-Ground Bin Considerations

As in the case of the in-ground bin installation, proximity to the wood chip burning appliance was a major consideration in locating the above-ground bin. The bin was designed to fit against the side of the house and the exterior was finished in cedar shingles which were stained to match existing structures elsewhere around the property.

4.2.7 Above-Ground Bin Design

The dimensions of the house, the location of the property boundaries and municipal set-back requirements determined the overall bin dimensions were 7.2 m (23.5 ft) in length, 1.7 m (5.5 ft) in width, and a height reducing from 2 m (6.5 ft) to 1.7 m (5.5 ft) for drainage off the roof. The volume of chips that could be stored is 22 m^3 (28.7 yds³); with hardwood chips having an average density of 224 kg/m^3 (14 lb/ft³), this represents a total mass of chips weighing 4.9 tonnes (10,900 lbs), or a half year's fuel supply to the house.

Bin loading is accommodated in one of two ways. Four hatches located along the roof of the bin permit pneumatic or

conveyor belt loading, and a single trap door in the end of the bin facing the street accommodates a ramp from the bed of a truck; chips may be shovelled or raked along the ramp and into the bin. Unloading is performed manually, with access to the bin through a combination of a door and a set of removable boards between the bin and the garage. Figures 4.2.3 to 4.2.5 show plan and elevation views of the structure.

4.2.8 Above-Ground Bin Costs

Site preparation costs were \$594. Material costs were \$1,357. Total rental was \$118. Labour, at \$4.00/hour for 112 hours and \$7.00/hour for 116 hours, was \$1,260. Overall cost was \$3,329. Not considering labour cost, and without the special problems encountered at this site, the bin cost could have been as low as \$1,625.

Several important differences exist between the in-ground and above-ground bin installations, making direct cost comparisons misleading. The in-ground bin was built one year earlier than the above-ground structure, at a time when building material prices, and therefore the bin's material costs, were lower. Secondly, the

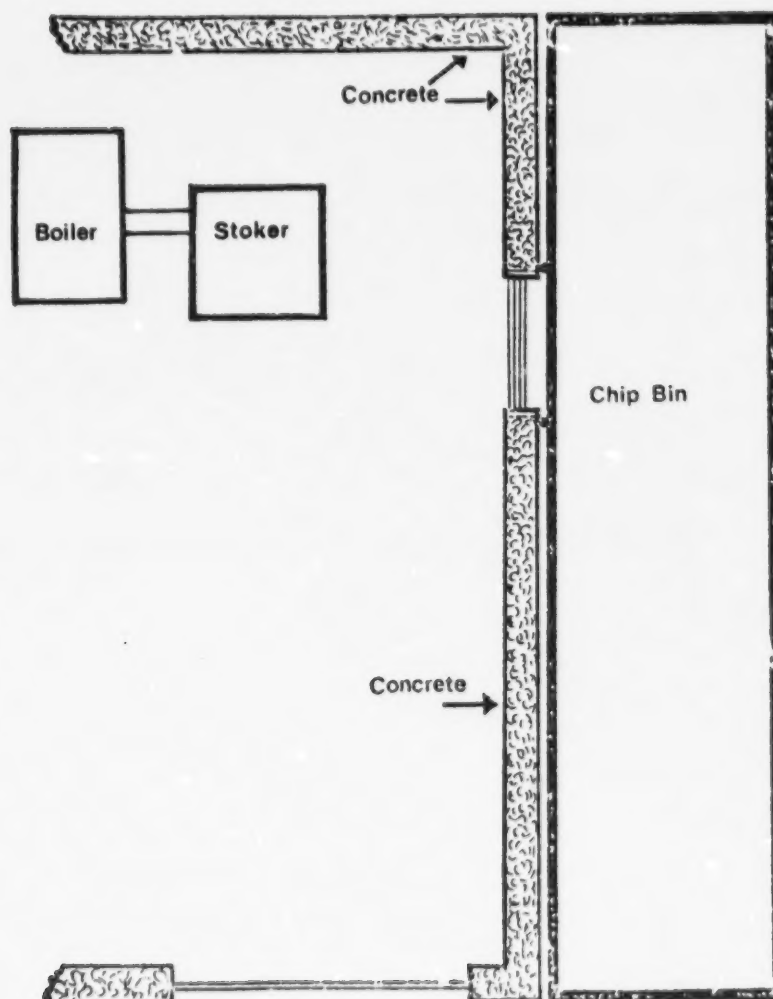


Figure 4.2.3. Plan view of above-ground chip home storage bin and stoker-boiler combination.

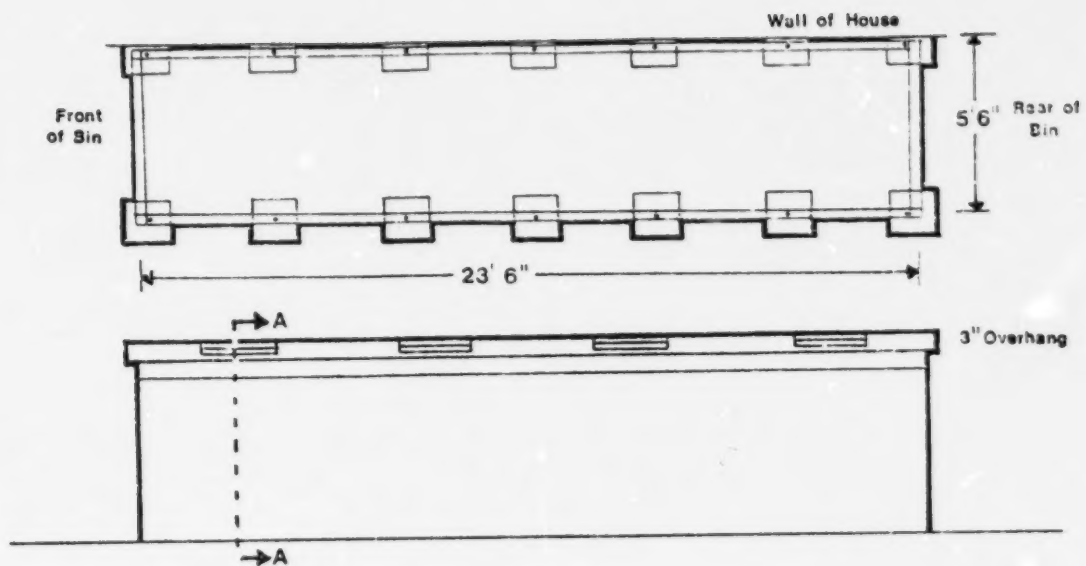


Figure 4.2.4. Foundation and longitudinal section view of the above-ground home storage bin. Section A-A is found in Figure 4.2.5.

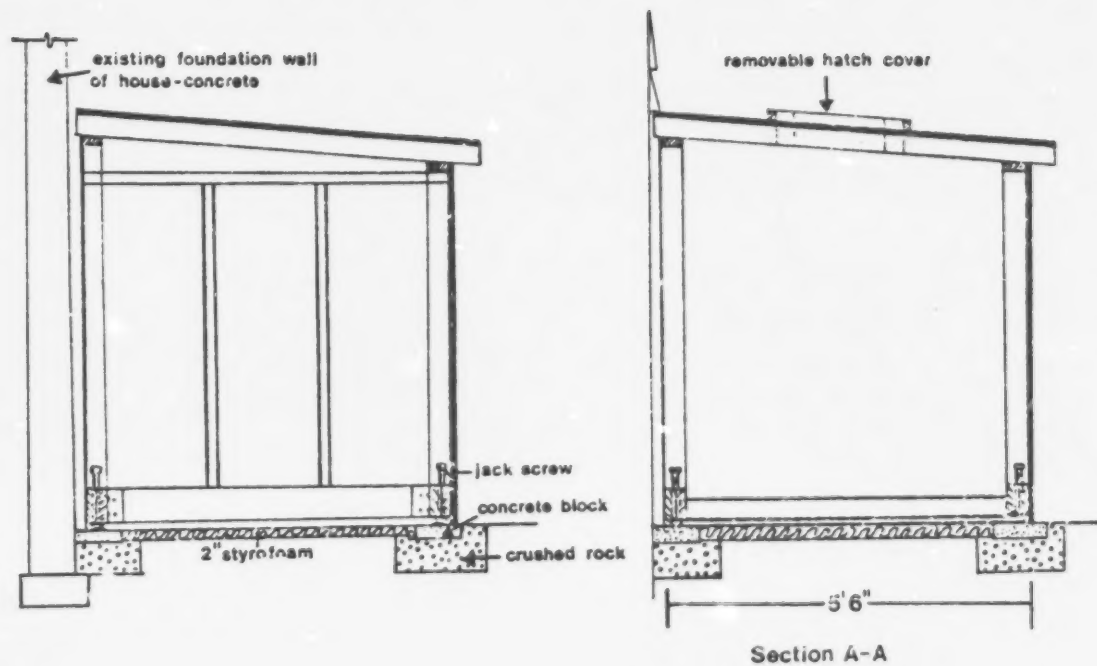


Figure 4.2.5. Sectional views of the above-ground home storage bin.

in-ground bin was cubic in shape, the most efficient design in terms of containing the maximum volume for the minimum wall area. The site location did not permit use of such a shape with the above-ground bin. Thirdly, the in-ground bin made use of the house foundation wall for one of its walls, while all four walls had to be constructed for the above-ground bin. Fourthly, the basement wall through which access had to be cut for the in-ground bin was of field stone and mortar; two men cut the opening in 4 hours using hammers and chisels, while the above-ground installation required twice the time and involved rental of specialized power tools. Finally, the above-ground bin can accommodate 22 m^3 (28.7 yds^3) of chips, for a storage capacity 70% greater than that of the in-ground bin.

4.2.9 Above-Ground Bin Operating Experience

The design of the bin anticipated routine availability of a chip delivery truck equipped with an on-board pneumatic or other mechanical unloading system. Such a truck was obtained for demonstration purposes from a contractor in P.E.I. and was able to deliver its full load of 12.7 m^3 (450 ft^3) in 30 minutes once the belt conveyor system had been put in place. Three men were

required to help unload the truck - one to oversee operation of the conveyors and two within the bin to pile chips coming off the conveyor to the greatest possible height. Almost two full truck-loads were required to fill the bin.

A self unloading truck is not ordinarily available and so, for the present, bulk deliveries are planned to be made using a truck having an open dump box. The truck will be backed up to the bin, its box partially raised, and chips will be shovelled over a short, plywood chute into the bin.

Unloading in order to fuel the wood chip stoker was done manually by shovelling chips into a large (75 l or 16 gal) plastic garbage can which then was weighed (as part of an ongoing heating system monitoring program) and dumped into the hopper of the stoker. This entire operation, including weighing, required 5 minutes.

4.2.10 Bin Conclusions

The bins built and demonstrated in this project are aesthetically acceptable and are an effective means for storing a practical quantity of fuel chips in a residential setting.

Loading the above-ground bin is a somewhat tedious and dirty job, but this is expected to change once appropriate delivery vehicles are available. A short-term solution involves use of a simple, light-weight belt conveyor to span the distance from the truck bed to any one of the bin hatches. Such a conveyor would eliminate the need for a man inside the bin to spread the load but would still require one man to feed chips from the load on the truck onto the conveyor belt. The in-ground bin is easily loaded. Each bin permits fuel chip storage without intruding on the available floor space and does not detract from the landscaping.

4.3 Processing Facility

It was recognized very early in our experience with residential-sized wood chip heating appliances that oversized fuel particles and large variations in fuel moisture content would interfere with appliance operation. The chippers used tended to produce a few oversized particles from the end of each bolt being chipped, regardless of the care taken with knife sharpness and control of in-feed speed. Attempts to produce chips from very small-diameter material resulted in many twig-like particles in the mass of chips produced. Wide variations in moisture content

led to non-uniform heat output in the appliance. Uniformity in moisture content is necessary to establish a fair retail price for the chips. For example, the heat energy in a tonne of green chips is approximately half that in a tonne of chips dried to about 20% moisture content. Further, experience and tests in both Scandinavia and New Brunswick indicated that, under certain conditions involving piled storage of moist chips (greater than 30% MC dry basis or 23% MC wet basis), disease-causing thermophilic fungi could grow and propagate. Consequently, it is necessary to both screen and dry chips intended for fuel use.

The chip harvesting and transportation systems used in 1982 and 1983 for CLEAR 1 to 5 inclusive and THIN 2 involved production of chips in container loads of about 30 m³ (1,000 ft³). It was necessary to provide a clean location at which to dump chips where they could be protected to some extent from the elements.

The wood chip fuel processing demonstration facility was designed to accept loads of green chips, screen them, dry them, and then store them in a protected area where they could be held until delivered to a customer.

4.3.1 Processing Facility Building Design

A review of available designs for bulk storage of dry granular materials led to consideration of Agriculture Canada horizontal silo plans. One such arrangement, identified on Agriculture Canada Farm Building Plan Service, Plan No. 7431, titled Pole Type Horizontal Silos (Cantilever Wall), appeared particularly appropriate; as shown on the plans, it offered an open-topped structure 24 m long by 12 m wide by 2.3 m high (80 x 40 x 7.5 ft) having a concrete slab floor and well-braced wood walls. The original plan was modified by constructing a partition wall down the middle of the structure, thus creating two compartments, each 12 m (40 ft) square. One of these, intended to receive green chips, was left uncovered to receive incoming loads of green chips. The second, intended as the storage area for dried chips, was increased in height by 2.4 m (8 ft) to provide vertical headroom of 4.7 m (15.5 ft) and was enclosed with a pitched roof; the vertical clearance thus provided enabled a large, wheeled, front-end loader (Caterpillar Model 930) to operate within the dried chip storage area for pile management and for subsequent loading of delivery trucks.

Immediately adjoining the dry storage section of the facility is the drying chamber. This structure resembles a large,

windowless, single car garage in layout with a full width and height vehicle entrance door at one end; it is shown in Figure 4.3.1. While the purpose of the chamber is to dry chips by forcing air through them, it also contains a significant inventory of chips and so is described in this section. Its drying performance is detailed in a later section. The drying chamber is sized to accept about 10 tonnes, sufficient to heat one house for a full year. It is a wooden structure having inside dimensions of 6.1 m long by 3 m wide by 4.1 m high (20 x 10 x 13.5 ft) and is topped with a pitched roof. The floor is a well-supported perforated steel deck located 200 mm (8 in) above a concrete slab. Front-end loader access to the chamber is accommodated via a ramp from ground level up to the perforated steel floor. The cavity under the floor is sealed tightly and connected by ductwork to an axial fan arranged to blow outside air in under the floor. Inside the drying chamber, the lower 2.4 m (8 ft) of wall, including the unloading door, is clad with tightly-fitted galvanized steel panels in order to ensure a durable, air-tight enclosure around a load of chips. The additional 1.7 m (5.5 ft) of interior height accommodates the head end of the loading conveyor and permits a man to stand on a full load of chips while spreading them to a uniform depth across the chamber.

Normally, green chips are not stored for any length of

time in the receiving section of the facility; that section is considered primarily as surge storage in order to accept chips as rapidly as they are delivered. As soon after delivery as possible, the chips are screened and dried before putting them into long-term storage. Total storage capacity, (considering only the drying chamber and the dry storage section of the facility) is approximately 475 m^3 (620 yds^3) of dried chips if the chips are piled 3.4 m (11 ft) high; this is sufficient fuel for ten or eleven houses. The exact volume depends on the height to which the chips can be piled, and this, in turn, depends on the size and power of the loader used. If they are piled to the rafters, (a height of 4.7 m or 15.5 ft), the volume of chips stored is 610 m^3 (800 yds^3) - a year's supply for thirteen or fourteen houses. Of course, the number of houses that can be supported by this facility is limited only by the production capacity of the drier; in most cases, at least a partial year's requirement of dry chips can be delivered directly to the end consumer rather than stock-piled at the facility.

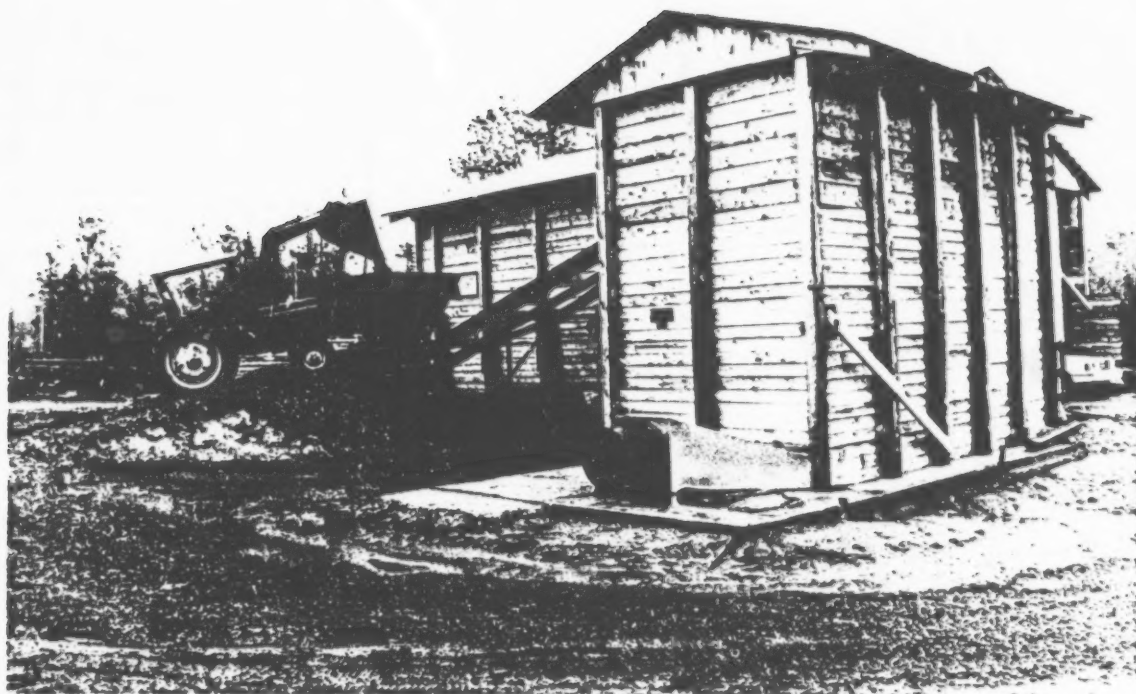


Figure 4.3.1. Another angle of the processing facility. The drying bin with fan in cylindrical housing is just to right center foreground and the opening to the dry storage building is just visible (it has a car in it).

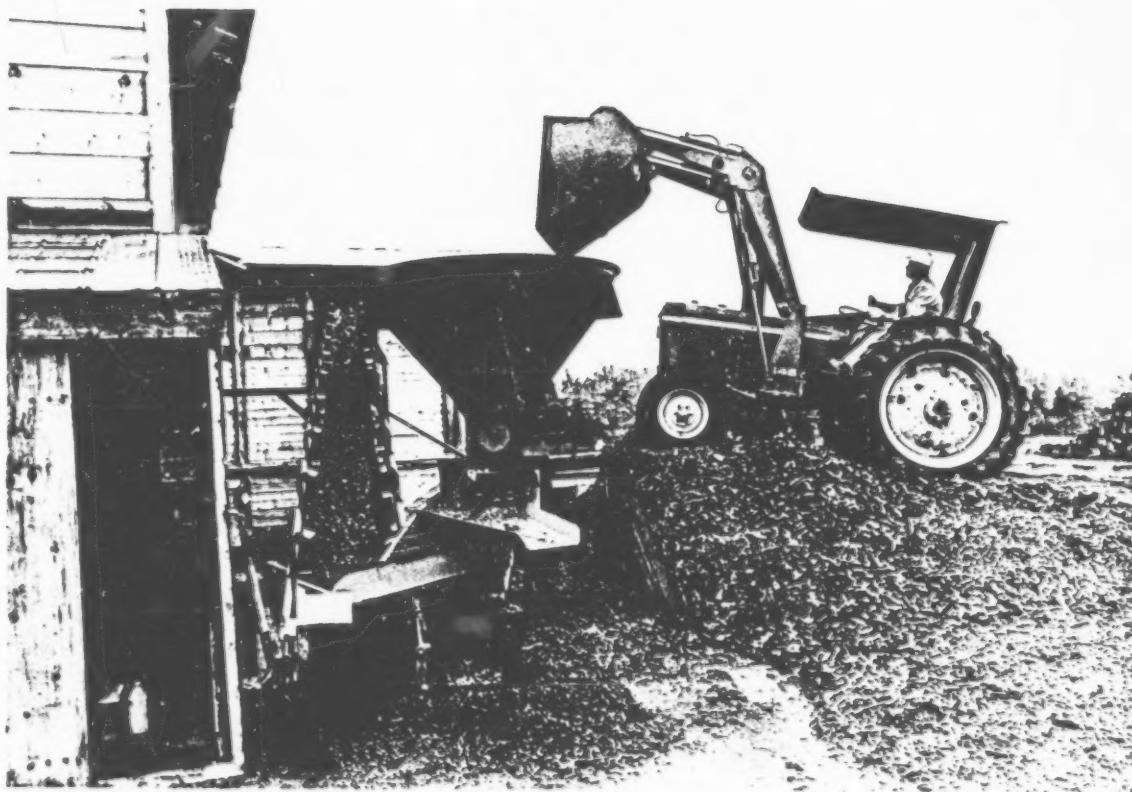


Figure 4.3.2. Screening the chips and loading the drying bin at the processing center. Oversize particles fall off chute pointing to the right and form the pile on the concrete pad. The pile of oversize particles in the photo is approximately the amount produced while screening a typical drying bin load of chips. The belt conveyor is carrying the screened chips up into the drying bin.

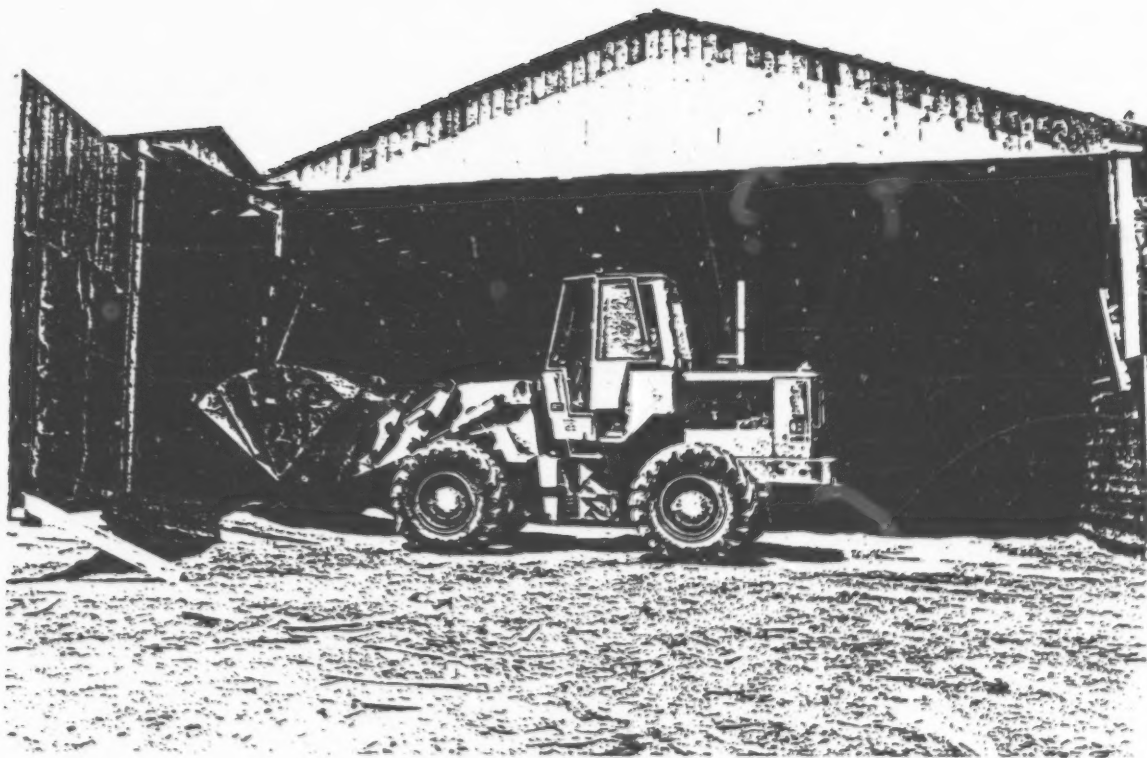


Figure 4.3.3. Drying bin being unloaded with front-end loader. Chips are being placed in the dry storage building behind the loader.

4.4 Storage at Maritime Forest Ranger School

During early stages of work with wood chip-burning appliances, chip fuel, predominantly hardwood, was prepared by personnel at the Maritime Forest Ranger School. The round-wood was piled in 2.4 m (8 ft) lengths and allowed to dry in unprotected piles outdoors for 9 to 12 months prior to chipping. The chips were blown from the chipper directly into one of two basement storage bins 7.3 m long by 3 m wide (24 x 10 ft). The chips within the bins varied in depth from 0.6 m to 1.2 m (2 to 4 ft). During chipping, one man was stationed in the bin to rake or shovel chips to a more or less uniform depth over the full bin area.

In addition to those chips in the basement bins, one lot was blown into two stalls in a small, unheated barn. The intent had been to use the chips as bedding for horses. However, the chips were found unsuitable for that purpose and so they were made available as fuel.

The floor of the basement is concrete and has, in all likelihood, no vapour barrier under it. The lowest 40 mm (1.5 in) of chips in either bin was always found to be saturated with water

(except at free edges of the pile) which had probably permeated through the floor and been unable to evaporate through the chips. The building is not weatherstripped, has no storm windows and is generally in such a condition that it would experience several air changes per hour. Consequently, despite moisture from the floor, the air in the building was sufficiently dry to promote drying of chips in the pile.

The walls of one basement bin, (known as the heated bin because it contained two wall-mounted steam radiators), were of concrete block. The second basement bin, designated the unheated bin, was a portion of the main basement framed off with 50 mm by 100 mm (2 x 4 in) lumber, and sheathed from the inside with flakeboard panels. The bin was open at the top and so was vented to the rest of the basement. In neither bin was there any attempt made to force-dry the chips.

The barn was constructed entirely of wood and had wood plank floors in the two sections where chips were stored. The building was sufficiently sound to protect the chips from the worst of the elements; nonetheless, chips taken from barn storage that had been next to an exterior wall were noticeably damp in several spots. The damp areas corresponded with places in the wall where it was possible for wind-driven rain to penetrate. In

the case of barn storage only, chips were piled to a depth of 2.4 to 3 m (8 to 10 feet).

Chips taken from either basement bin within a few days of chipping had moisture contents of around 50% dry basis (33% wet basis). Chips removed from the heated bin over approximately four months, following storage of at least five to six weeks, had dried to an average moisture content of 21.5% dry basis (17.7% wet basis). Those taken from the unheated bin had dried to 36.6% dry basis (26.8% wet basis), and those from barn storage had dried to 20.0% dry basis (16.7% wet basis).

Chips at the top of the pile were always the driest, while those at the very bottom were saturated with water. One spot-check of chips in the heated bin revealed moisture contents ranging between 12.8% and 13.1% dry basis (11.3% and 11.6% wet basis) at the top surface of a 1.2 m (4 ft) pile and 21.3% dry basis (17.6% wet basis) 0.6m (2 ft) below the surface.

4.5 Screening - Maritime Forest Ranger School

The chips contained a small fraction (approximately 3% by weight) of oversized cards, slivers or long, twig-like pieces.

Such materials cause handling problems in both mechanical and manual conveying systems during production and, especially in the residential-sized stokers, immediately prior to being burned. The oversized pieces tend to jam the augers in screw conveying mechanisms. Long strands of twig-like material, on the other hand, make manual shovelling very difficult, and even more important, they tend to plug the entry of normal chips into the screw conveyors used to feed material into the furnace grate. Screening was required, therefore, to reduce the amount of such particles to a tolerable level, if not totally eliminate them.

4.5.1 Screening by Hand

When chips were made from sections of tree stem, the resulting oversized pieces were usually easy to see and to remove manually, either when reclaiming chips from the chip bins or during routine tending of the stoker. Inevitably, some pieces escaped detection and found their way into the stokers. These pieces either caused jams and were removed once the jam occurred, or they accumulated over time in the hopper of the stoker until they partially or totally blocked the flow of normal chips to the fire. This caused the fire to either burn too low or to go out. At such times, the only recourse was to empty the hopper and discard the oversized particles.

4.5.2 Manual Bulk Screening

A tonne of chips made, as an experiment, from small-diameter woody material such as branches and alders was found to contain a small proportion (2% to 4% by weight) of long, thin, twig-like pieces 2 mm to 7 mm (1/16 in to 5/16 in) in diameter and up to 300 mm (12 in) long. Such pieces greatly increased the effort required to shovel chips out of storage and to subsequently handle them. Consequently, a crude but reasonably effective screen was made using 40 mm (1-1/2 in) mesh chicken wire stretched over a wood frame 1.2 m wide by 1.8 m long (4 x 6 ft) angled at about 45 degrees to the ground. Screening involved throwing several shovelfuls of unscreened chips onto the screen, then shaking the screen and removing the acceptable, small particles from beneath it. Periodically, it was necessary to tip the screen vertically to shake oversize pieces out of the mesh. The process of manually screening chips was very time-consuming, dirty and tiring, and led to a decision to avoid chipping further supplies of small-diameter material until such time as a mechanical screening system was available.

4.5.3 Screening at Processing Centre

In view of experience gained with unscreened chips and attempts to screen manually, it was decided that any fuel wood chip processing facility should include a screening operation through which all chips would pass. The processing plant built and operated by this project includes a screen as part of a vibratory conveyor used in delivering chips to the drying chamber. Chips are taken from the green storage pile by a front-end loader and are put into a metering bin. This bin feeds raw chips at a uniform rate onto a 6 m long by 0.6 m wide (20 x 2 ft) vibratory conveyor to which has been added a perforated steel plate. The holes in the plate are 38 mm (1-1/2 in) in diameter, and are arranged in an offset pattern. The plate is located 150 mm (6 in) above the bottom of the conveyor trough. Chips falling from the metering bin land on the perforated plate and, due to the horizontal shaking motion of the conveyor, start to move over the surface of the plate. Chips of acceptable size fall through the plate and are carried along on the bed of the conveyor trough, while oversize pieces remain on the plate and are discharged to a waste pile. Small chips are discharged onto a belt conveyor which takes them to the drying chamber. The metering bin and vibratory screen/conveyor system is shown in Figures 4.5.1 and 4.5.2.

4.6 Drying

Part of the UNB project investigated and demonstrated the drying of fuel chips. As fuel, dry chips have a number of advantages over wet chips. Some of these advantages are as follows.

1. The amount of heat recoverable during combustion is greater if dry chips (10% to 20% MC) are burned. An analysis revealed that up to 40% more oven-dry wood fiber may be needed to meet a residential heat load if green chips are burned instead of dry chips. Table 4.4.1 provides a summary of the results of this analysis for a range of fuel conditions and combustion system performances.

2. For a given heat requirement, less fuel storage space is required using dry chips. Table 4.4.1 illustrates the increase in annual storage volume for a typical New Brunswick single family residence.

3. Drying fuel chips as soon as possible after chipping prevents or inhibits fungal growth, especially in the case of whole tree fuel chips. Fungi spore concentrations are therefore avoided or controlled, minimizing any adverse health impact.

4. By drying, substance losses from decay and, therefore, post-chipping heating value loss, can be avoided.

5. Combustion temperatures are higher when dry chips are burned. With proper burner design and operation, oxidation is therefore more complete and carbon monoxide and particulate pollution emissions are reduced relative to wet chip combustion.

6. Chips dried to below the fiber saturation point (about 30% dry basis) can be stored within inhabited buildings since excess winter humidity levels and associated problems are avoided.

7. Dry chips are easier to handle. They flow more freely than wet chips under most circumstances. Also, chips dried below the fiber saturation point don't freeze into solid masses.

There is a fuller discussion of the advantages of dry wood fuel in the literature.

There are two basic choices about when to dry; (a) before chipping, or (b) after chipping. Both these options were investigated.

4.6.1 Drying Before Chipping

For this case two options were considered, namely, transpirational (sour felling) and roundwood drying. Data obtained by sampling and determining moisture content by the oven-dry method showed these drying techniques to be limited in their usefulness. Long times are required, and then only partial drying is achieved. For example, in the harvesting trial THIN 1, hardwood thinnings cut the previous summer and allowed to lie on the site for a year were gathered and chipped. The moisture content at felling was 70% dry basis and one year later about 45%. Similarly, 1.2 m (4 ft) and 2.4 m (8 ft) hardwood bolts seasoned over one year in a wood yard had about the same initial and final moisture contents. Other noted limitations were:

1. Both transpirational and roundwood drying have an inventory cost associated with the long drying times between felling, harvesting and final use.
2. Transpirational drying detracts from harvesting system productivity because of the need to fell and harvest in two separate operations.
3. Large quantities of wood dust are produced when dry wood is chipped.

4. Approximately 10% more energy is required to chip dry wood than green wood.

In view of these limitations, drying before chipping was considered less promising than drying after chipping. Consequently, efforts were focused on the latter.

4.6.2 Forced Air Chip Drying

With moving air surrounding a wood chip, drying is controlled by the condition of the air. Air temperature and relative humidity are the most important parameters. Flow must be sufficient to remove saturated air as the moisture moves out of the chip. Wood chips have a large surface-to-volume ratio, and only a small distance for moisture to travel. Diffusion of water from the interior of the chip to its surface is, therefore, not usually the controlling factor in chip drying as it is in most wood drying. Providing sufficient dry, warm air will cause rapid drying. The rapid drying means that as air moves through a bin in one direction, the first chips that the air contacts will rapidly dry to moisture equilibrium with the air. Air passing through these chips later will not begin to pick up moisture until it contacts wet chips further along the flow path. In this way, a "drying front" is established. Chips upstream of the drying front are dry and those downstream have essentially saturated air travelling around them so that no drying occurs. Drying takes place only in the drying front, which moves through the bin in the direction of the air flow.

As the air picks up moisture from the chips, the temperature drops. The greater the drying capacity (moisture-holding potential) of the air, the greater the temperature drop. This allows simple progress monitoring of drying and drying end-point. Before the drying front, the air will be at

inlet temperature. After it, the air will be cooler. When the binful is dry, exit air will be the same temperature as ingoing.

Providing there is sufficient air flow, the drying capacity of the bin is dependent upon inlet air conditions and the amount of water which must be evaporated and carried away. The amount of water to be evaporated can be calculated from the quantity of chips in the bin and their average moisture content. Bins using outside air depend up on weather conditions, so that weather records provide data for computing their air-drying potential. Dry and wet bulb temperatures are available for each hour of the day and each day of the year, for many years. Averaging these over several years for a particular place allows the use of psychrometric charts to calculate air-drying potential for specific hours, days and months. An example for each hour of the day for the month of June is given in Table 4.6.1. The best hours for drying during the month of June are 9:00 or 10:00 AM to 8:00 or 9:00 PM. Choosing 10:00 AM to 9:00 PM as the time when it is most advantageous to run a drying fan, an average air-drying potential for that interval can be calculated. In the example, 418 m^3 ($14,761 \text{ ft}^3$) of air is required to evaporate 1 kg (2.2 lbs) of water. The same exercise can be done for each drying month. Results are shown in Table 4.6.2.

The average moisture content of chips to be dried can be estimated from experience, or, if green chips are used and the species mix is known, data from the Forest Products laboratories will give reliable estimates. If rough estimates only are needed, the following can be applied as a general rule of thumb: hardwoods average 70% MC green and softwoods 100%. The average for chips stored several months outside on a concrete pad at the processing centre has been 190% MC. The moisture content at the end of the drying cycle can be calculated from weather data. Wood in equilibrium with air, having a specific temperature and relative humidity, has a

known MC, called the equilibrium MC. Using average dry bulb and wet bulb temperatures over the drying period (such as those given in Table 4.6.1), a final MC can be determined. The results of such determinations over the drying months and during selected drying periods each day are given in Table 4.6.3. Chips in a drying bin are seldom dried completely up through the load. Because of flow irregularities through the pile, a few wet pockets near the top usually remain. Some rewetting during handling frequently occurs. The normal end-point of drying is often nearer the top of the range than the mean. The delivered MC of the chips often approaches 20%, which is why this MC is standard in the report.

Knowing the resistance to air flow in a column of chips and the flow-pressure characteristics of a fan allows calculation of the amount of air which will move through a given amount of chips in a certain time. An example of a grain-drying fan flow-pressure curve is given in Figure 4.6.1. The same fan is used, but driven with two different motors. The 5 hp model was used in the project bin. Assuming negligible pressure drop through a bin floor, preliminary tests indicated that a static pressure of 1.5 to 2.0 inches of water gage (375 to 500 Pa) could be expected through a 2.4 m (8 ft) column of chips. This would give about $3.9 \text{ m}^3/\text{s}$ (8,300 cfm), or $0.22 \text{ m}^3/\text{s per m}^2$ (41.5 cfm/ft²) of floor area for a 3 m by 6 m (10 x 20 ft) bin. Measurement of pressure above the project bin perforated floor (3 mm holes, 30% open area) with a load of chips in the bin showed negligible pressure drop.

Drying times for the project bin, estimated from the above data and calculations, suggested that 10 to 40 days would be required to dry a load, with the variation resulting from differing initial moisture contents and times of year.

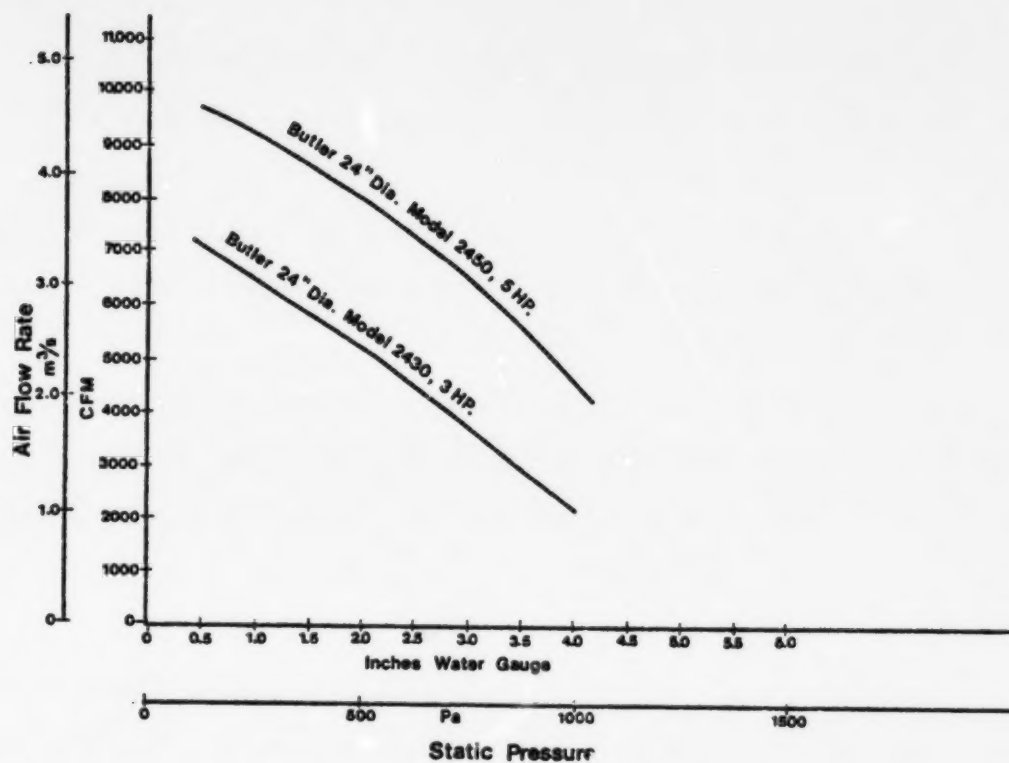


Figure 4.6.1. Performance curves for the grain drying fan used in the project drying bin. The 5 hp model was used.

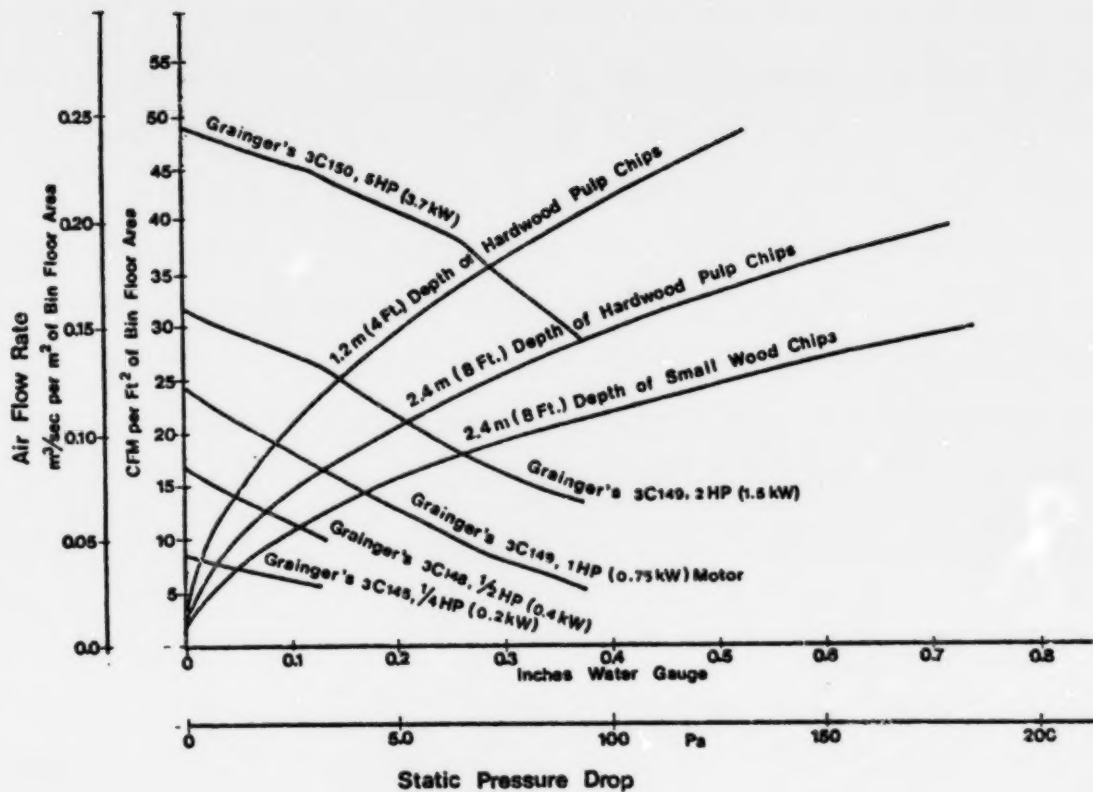


Figure 4.6.2. Some other fan possibilities for drying fuel wood chips.

Results of four drying runs with the project bin are given in Tables 4.6.4 and 4.6.5. Best drying occurred early in the season. In load 3, the fan was allowed to run continuously. Fan energy consumption to dry a unit weight of chips was markedly higher in this case than those where the fan ran during the best 12 drying hours of the day. Table 4.6.5 shows that labour accounted for a large proportion of the cost to dry the chips.

The results suggest that there exists a sound basis for estimates needed in designing chip drying bins similar to the one demonstrated. There is also considerable room for experimentation and demonstration to try to optimize drying times, labour costs and drying energy consumption.

Table 4.6.1. Average hourly drying capacity of air for month of June.
Temperatures are means for each hour of the day during the
period 1957-1966 for Fredericton, N.B.

Hour of Day	Temperatures		Drying Capacity of Air		Air to Dry Unit Mass
	Dry Bulb °C	Wet Bulb °C	g/m ³	gr/ft ³	m ³ /kg
00	13.1	11.1	0.870	0.380	1149
01	12.4	10.8	0.680	0.297	1471
02	11.9	10.5	0.680	0.297	1471
03	11.4	10.2	0.524	0.290	1908
04	10.9	9.8	0.526	0.230	1901
05	10.6	9.6	0.352	0.154	2841
06	11.2	10.1	0.703	0.307	1422
07	12.5	10.9	0.874	0.382	1144
08	13.8	11.7	1.041	0.455	961
09	15.7	12.7	1.380	0.603	725
10	17.3	13.3	1.886	0.824	530
11	18.6	13.8	2.220	0.970	450
12	19.6	14.2	2.551	1.114	392
13	20.3	14.6	2.716	1.187	368
14	20.9	14.7	2.879	1.258	347
15	21.2	14.8	3.041	1.329	328
16	21.2	14.8	3.041	1.329	329
17	20.8	14.7	2.886	1.261	347
18	20.2	14.4	2.721	1.189	368
19	19.2	14.2	2.384	1.042	419
20	18.1	13.8	2.053	0.896	487
21	16.2	12.9	1.549	0.677	645
22	14.9	12.2	1.213	0.530	824
23	14.1	11.8	0.867	0.379	1153
Average of twelve best hours (10:00 - 21:00) =					418

Table 4.6.2 Mean monthly air drying potentials from weather data for the 12 best hours of the day (9:00 am to 9:00 pm).

Month	Drying capacity of air		Air volume required to evaporate unit mass of water	
	g/m ³	gr/ft ³	m ³ /kg	ft ³ /lb
April	1.586	0.693	631	10106
May	2.291	1.001	437	6990
June	2.487	1.087	418	6440
July	2.178	0.952	459	7351
August	2.098	0.917	477	7630
September	1.730	0.756	578	9258
October	1.204	0.526	831	13318

Table 4.6.3 Mean monthly temperature and wood equilibrium moisture contents(EMC), 9:00 a.m. to 9:00 p.m. daily.

Month	Dry Bulb		Wet Bulb		Depression		EMC %
	°C	°F	°C	°F	°C	°F	
April	6.7	44	3.3	38	3.4	6	11
May	14	58	9.4	49	4.6	9	10
June	19	66	14	57	5.0	9	11
July	22	71	17	62	5.0	9	12
August	21	70	16	61	5.0	8	12
September	16	61	13	54	4.0	7	13
October	10	50	7.2	45	2.8	5	14
Mean range							12 10-14

Table 4.6.4. Results of 1983 drying trials in 45m³ (1600 ft³) bin with 3m by 6m (10 ft by 20ft) perforated floor aerated with 5 hp fan.

Dates	Load	Days	Hrs/day fan on	% MC Begin	End	Weight Water Evap. kg(lbs)	Energy for Evap. MJ (10 ⁶ Btu)	Fan Energy Used KWH (MJ)	Evap. Energy Fan Energy
18 May- 22 June	1	35	12	76	15	4790 (10536)	11800 (11.2)	775 (2740)	4.22:1
28 June- 15 July	2	17	12	73	13	5190 (11423)	10540 (10.0)	625 (2130)	4.66:1
20 July- 19 Aug.	3	30	24	73	18	3950 (8648)	9700 (9.2)	2375 (8570)	1.14:1
19 Aug.- 27 Sept.	4	39	12	92	17	4550 (10012)	11170 (10.6)	1350 (4850)	2.30:1

Table 4.6.5. Time, energy and monetary costs to dry the loads of Table 4.6.4.

Load	20% MC Tonnes	Fan KWH to dry	\$ KWH	Fan Energy Cost \$	Man-hours			Labor Cost \$	\$ Cost per 20% MC tonne to Dry Handle Total (labor)		
					Load	Unload	Total				
1	9.0	775	.04	31	8	2	10	74	3.40	8.22	11.62
2	8.0	625	.04	25	18	2	20	158	3.13	19.75	22.88
3	8.4	2375	.04	95	12	1	13	96	11.30	11.45	22.75
4	7.1	1350	.04	54	12	1	13	96	7.60	13.54	21.15

5.0 Distribution

5.1 Introduction

A major constraint of any wood chip fuel distribution system relates to the low energy density of wood chips. A typical fuel oil delivery truck can carry about 9,000 l (2,000 Imperial gal), which is sufficient to make deliveries to as many as twenty residential consumers. The same size truck can carry 8 tonnes (8.8 tons) of wood chips, sufficient to make up to eight deliveries of roughly equivalent amounts of energy. Therefore, based on vehicle capacity, the wood chip delivery operation is about 40% as efficient as the equivalent oil delivery system. Delivery time from truck to storage bin is also somewhat longer than that for a similar amount of energy delivered in the form of oil, although this depends to a great extent on the manner in which delivery can be made; a dump truck loading a below-ground bin can make a delivery in a very short time, while a similar load to an above-ground bin can take much longer.

Chip bins should have larger energy capacity than residential oil tanks because unloading times into some bin types are long. In order to reduce the handling costs that would be

associated with relatively frequent deliveries of one or two tonne loads of wood chip fuel, a strategy of making infrequent deliveries of 4 to 6 or more tonnes at a time has been adopted. Such a strategy requires that each residence has a fuel bin capable of storing from a third to a full year's supply of wood chips. This then simplifies delivery truck scheduling, reduces the quantity of fuel held in inventory by the fuel supplier and reduces the cost of the fuel to the consumer.

5.2 Utility Trailers - Loose and Bagged Chips

Small utility trailers have been used in the project to transport bags of chips several kilometers from storage to a home furnace installation and to carry loose chips from a storage bin about 50 m (150 ft) to the furnace. The loose chip trailers had high sideboards that allowed them to carry about 3 m^3 (4 yds^3) of chips. Such a trailer could typically be loaded by one man in 45 minutes using a 100 mm (4 in) grain auger. Unloading down a chute into the stoker hopper took about 15 minutes daily over the 5 to 7 day period during which such a trailer would provide chips in winter weather. When an underground bin that held more than the capacity of the trailer was constructed complete trailer unloading took 15 to 20 minutes. The utility trailers were the same ones used to transport chips the 1 km (0.6 mi) distance from the

harvesting site to storage during the slash recovery part of the project (SLASH 1 and 2).

Under circumstances where householders could collect their own chips from a processing centre, the following example illustrates costs involved. Chips have been delivered to one home heating system in this project in 16 kg (35 lb) woven polypropylene bags. The bagging operation was completely manual, requiring two people, and was integrated with loading the bags on a trailer. During filling, a bag was supported in a holder while one man shoveled chips into it directly from the storage bin. Since the dried chips are relatively light and easily handled, a shovel with a No. 8 aluminum blade was used; this permitted rapid bag filling, with 5 shovelfuls required per bag. Filled bags were removed from the holder and passed to the second man who tied a string around the neck of the bag and loaded the bag onto a small cart. Once three bags were on the cart, the second man wheeled the cart to a dock and loaded them onto a utility trailer. The trailer was fitted with extended sides to accommodate a 36 bag load without need for special tie-down straps. The production rate of this system was 40 bags per hour and was limited by the rate at which bags could be filled. Better system balance would be achieved with two fillers and one tier/loader; however, because combined car and trailer capacity was 40 bags and the normal

delivery was just one such load at a time, a second filler was never used.

Labour required to fill and load 40 bags was 2 man-hours. At a rate of \$4.00 per man-hour, the cost was \$8.00, or 20 cents per bag. This amounts to \$12.50 per tonne of dried chips (\$11.45 per ton).

Delivery cost for a 40 bag load is based on a flat rate mileage cost of 25 cents per km (40 cents per mi) for a compact passenger car and trailer combination; travel is charged for the round trip, that is, to deliver the bags and to return to the storage site empty. For the nome in question, the round-trip distance was 8 km (5 mi) with a vehicular cost of \$2.00. Added to this was a half hour travel and unloading time for each of two men, totalling one man-hour at \$4.00. The total delivery cost, therefore, is \$6.00 for the 40 bag load, or \$9.40 per tonne (\$8.60 per ton).

The total handling and delivery cost using a chip bag/utility trailer system that can handle 40 bags of 16 kg (35 lb) each at a time - a load of only 0.64 tonne (0.7 tons) - is \$21.90 per tonne (\$20.05 per ton). It is important to note, however, that the equipment and skills involved are readily

available to many homeowners and that, save for the vehicle operating costs, the labour component could be supplied entirely by the homeowner at no charge. The actual out-of-pocket cost then reduces to running/owning costs of the car and trailer - in this case \$2.00 - for a fuel delivery cost of \$3.13 per tonne (\$2.86 per ton).

5.3 Self-Unloading Trailer with Drying Capability

As a result of experience in this project, a Fredericton sawmill owner constructed a trailer with a false, perforated bottom and an auger for unloading. The trailer is designed for highway travel. It holds about 14 m^3 (18 yds^3), enough to supply a typical home for a few months in the winter. Exhaust hot air from the sawmill compressor provides drying performance considerably beyond that possible under ambient conditions, especially in the spring and fall. Experience with this trailer is limited, but it appears that unloading time will be about half an hour.

5.4 Dump Truck

A 3-ton truck with a dumping body has been used for one winter to provide fuel to the Fredericton home with the

underground storage bin. The truck was a flatbed normally used for delivering lumber, but with sideboards installed, it would hold just enough (13 m^3 or 17 yd^3) to fill the bin. A front-end loader could fill this truck in less than ten minutes. Unloading times ranged from 5 to 20 minutes with two men involved, one to control the sliding of chips into the bin, and the other to distribute the chips as the bin neared filling. The shorter unloading time occurred with a smaller than usual load, so that almost no distribution was necessary. Probably 10 to 15 minutes would be typical unloading times with an experienced crew. Such a delivery scheme is simple and effective.

5.5 Conclusions

During the life of the demonstration project, four separate methods of chip distribution were tested and evaluated. In each case, the method was carried out on a small scale using available transportation and local labour. Table 5.1 shows the elements of cost involved and the cost per load and per tonne for comparison purposes.

Two major assumptions have been made. First, a total delivery distance of 24 km (15 mi) has been used for each method. This distance has been arbitrarily chosen to represent the average

round-trip distance that a homeowner would have if resident in the Fredericton metropolitan area and obtaining wood chips from a central processing facility.

The second assumption concerned labour costs. For the first two methods, these were set at \$4.00 per hour, the actual cost involved in each case. In the third and fourth methods, a rate of \$7.40 was used, on the assumption that these methods involved commercial operations where casual labour rates would not apply, and therefore, some fringe benefit and overhead costs would have to be added.

Nevertheless, it is clear that the labour-intensive methods are not as cost-effective as the larger-volume, semi-mechanized methods. However, the labour-intensive methods can benefit from the ability of the consumer to supply the labour himself, at no direct cost to himself. Under this assumption, the distribution costs fall to \$8.97 per tonne and \$9.37 per tonne respectively, bringing these methods into competitive range with small commercial operations.

Larger-volume, fully-automated vehicles using pneumatic loading and delivery systems would reduce the costs further, especially if consumer storage facilities were designed to accept

quick-connect couplings which were easily accessible from the road, offering the same ease of delivery now enjoyed by fuel oil distributors. However, the investigation of such a system was not part of this demonstration project.

TABLE 5.1 SUMMARY OF WOOD CHIP DISTRIBUTION COSTS

Distribution Method	Cost Basis (a)	Cost per Load	Cost per Tonne
1. <u>UTILITY TRAILER</u> Loose chips	3 cu.m/load (b) 0.75 man-hrs loading 0.33 man-hrs unloading Transport = 24km x 25c/km	\$3.00 1.32 6.00 <u>\$10.32</u>	\$15.43
2. <u>UTILITY TRAILER</u> Bagged chips	16kg/bag; 40 bags/load 2.0 man-hrs loading 1.0 man-hrs unloading Transport = 24km x 25c/km	\$8.00 4.00 6.00 <u>\$18.00</u>	\$28.13
3. <u>SELF-UNLOADING TRAILER</u>	14 cu.m/load 0.2 man-hrs loading 0.5 man-hrs unloading Transport = 24km x 75c/km	\$1.48 3.70 18.00 <u>\$23.18</u>	\$7.43
4. <u>DUMP TRUCK</u>	13 cu.m/load 0.2 man-hrs loading 0.5 man-hrs unloading Transport = 24km x \$1.75/km	\$1.48 3.70 38.00 <u>\$35.18</u>	\$12.13

6.0 Arvin Chipper

One of the off-shoots of the small-scale wood chip harvesting project was the design, manufacture and demonstration of a portable, tractor-driven disc chipper. Such chippers were offered by several European manufacturers, but all were deficient, either from an operational standpoint or in terms of rapid availability of spare parts. Acquisition of a chipper was a component of the harvesting project and so, in light of the foregoing, it was decided to pursue local manufacture.

Following consultation with the New Brunswick Department of Trade and Commerce and contact with several possible manufacturers, Arvin Special Machinery of Chatham, N.B. was engaged to fabricate a prototype chipper with design support provided by the New Brunswick Research and Productivity Council.

6.1 Chipper Specifications

The machine specifications provided to the manufacturer were as follows:

- minimum capacity 6.5 m³ (230 ft³) solid wood per hour
- power input 45kW (60hp) at 540 rpm
- disc rotational design speed - 540 rpm
- maximum " - 700 rpm
- chip size to be predominantly 13mm (0.5 in) but adjustable to 30mm
- weight 725 kg (1,600 lbs) maximum
- conveying capability to lift chips vertically 7 m (23 ft)
- discharge chute adjustable - horizontally over 360 degrees
- vertically over 135 degrees
- self-contained hydraulic system
- hydraulically driven infeed rolls
- forward/neutral/reverse infeed roll control
- panic infeed roll stop/reverse control
- 250mm x 250mm (10 in x 10 in) infeed opening
- converging infeed chute
- horizontal infeed
- convenient infeed height
- must accommodate trailer hitching to tractor while chipping
- must use standard three-point hitch tractor mounting
- four knives on disc
- one set spare knives
- powered grinding wheel for knife sharpening

Detailed design work began in December 1981, and the prototype chipper underwent initial tests in late July, 1982. The tests indicated that several modifications were required, following which, the machine was considered ready for fully operational.

6.2 Operating Experience

Project priorities precluded planned extensive field testing of the chipper since it was undergoing modification when much of the harvesting work was in progress. However, several field operations did make use of the unit, with mostly positive results.

Several cords of wood were chipped as part of public demonstrations at the Maritime Forest Ranger School during Firewood Day in September, 1982 and at the UNB Intercollegiate Woodsmens Competition in October, 1982. Twenty cords of sawmill slabs were chipped at the wood chip processing centre during the winter of 1982. More rigorous testing of the chipper occurred during the summer of 1983 when a silvicultural contractor used it for a time in a thinning operation (THIN 2). The contractor indicated that the Arvin chipper was easier and safer to use than the Bruks 720 chipper normally used.

As could be expected with a prototype machine, several problems became evident during field testing. It was discovered that the disc shaft thrust bearing permitted 2mm (3/16 in) axial play; this required that care be taken prior to setting the knife clearance to ensure that the disc/shaft assembly had been pushed fully towards the counter knife; a closer tolerance disc shaft thrust bearing should overcome this problem. Another problem, only encountered during production chipping, involved chips becoming impacted between

the rotating disc and the housing which encloses it. As chips became wedged in the narrow, converging space, they exerted a braking action on the disc. The problem was resolved by modifying the housing and the chip blower inlet.

SUMMARY OF OPERATING COSTS

Project harvesting and transportation equipment and their fixed and operating costs per hour are shown in Table 7.1. Detailed cost breakdowns of each operation are shown in Tables 7.2 through 7.11.

Figure 7.1.2 illustrates the average components of the total cost from the 9 test blocks. Direct labour was 50% of the total cost. The other cost components were 19% for operating costs, (fuel, lubricants, repairs etc. required to operate the machinery), 19% for fixed costs (costs associated with ownership or rental of the machinery) and 12% for transportation (delivery of the wood chips from the roadside landing area to a central storage point).

Individual blocks varied fairly widely around these averages. Some examples of the reasons for the variability follow.

The lowest labour component, 41%, occurred in block CLEAR 5 where the sum of fixed and operating costs (50%) was highest for all blocks harvested. Also, this block was close to the chip storage area so transportation costs were only 9% of the total. The highest labour content, (69%), occurred in block THIN 2 where the sum of fixed and operating costs was the lowest (19%) of all blocks. Labour was traded for capital in this case. The experience from this project was that labour costs varied up to 20% above the average but only 10% below the average. Equipment costs varied approximately 10% above the average but 20% below average. Given the wide possible variety of forest types, harvesting methods and the cost variability the project experienced, wood-chip harvesting entrepreneurs could expect considerable room in which to maneuver.

Transportation costs varied from a low of 5% to a high of 19% over the 9 blocks harvested. These variations are a direct result of the distance between the harvesting block and the storage area.

During this project nearly 140 tonnes of wood chips were produced. The average production was \$148.79 per tonne. This includes chip transportation to the processing centre in the suburbs of Fredericton.

There was considerable cost variation per tonne. The range was \$104.10 per tonne in block CLEAR 2 to \$198.23 per tonne in block THIN 1. This represents almost \$50 per tonne difference above and below average.

The harvesting cost variations were caused by variations in man and machine time per unit of production. The variations can be seen in Table 3.4. The average time required to harvest one tonne in the 9 blocks was 10.59 man-hours, with the range from 5.89 hours per tonne to 16.43 hours per tonne.

We have so far costed all of the operations in this project for single-purpose harvesting, with all of the cost applied to the chips. There may be wood chip harvesting operations with more than one objective; for example, the last thinning operation (THIN 2), was carried out primarily to thin the stand, thereby improving its quality and appearance. Because labour was applied to thinning, the only costs directly related to chip production were the costs of equipment used for chipping and for transporting chips to the processing centre. These costs are outlined in Table 7.11. Chip cost to the project in this instance was \$38.67 per tonne. This example illustrates the benefits of integrated harvesting, where costs can be shared among products and objectives.

There are costs for drying, screening, storage, and final delivery of ready-to-use chips. This demonstration project operated, and monitored the

operating costs, of a chip processing and storage facility. Details of these costs are shown in Table 7.13. The processing capacity of the facility as it has been operated so far, is 440 tonnes per year, which would serve 40 average residences in the Fredericton area. With greater operating experience and relatively small modifications to the plant and its operation, a substantial increase in throughput is probable. The cost of acquiring the use of the land on which the facility is located is not included in the cost calculation, as is accepted practice. Since land is not a depreciable asset, its full value is recoverable on termination of the operation. A 12 km (7.5 mi) delivery distance has been used. This distance allows the facility to service any home within the metropolitan area of the City of Fredericton. Delivery cost is based on 4-tonne loads per journey. It is probable that a commercial operation would have a larger truck able to service several customers in one trip. This could lower delivery costs. Unloading could be streamlined, thereby improving the delivery schedule.

The estimated cost of ready-to-use wood chip fuel for automatic stokers is obtained by adding processing and delivery cost, average harvesting and chipping cost, plus a profit margin. The overall estimated cost could then be compared to that of fuel oil or electricity.

Table 7.1
Harvesting Equipment and Costing Rates

Equipment	Purchase Cost	Machine Rate	
		Fixed Cost (Per Hour)	Operating Cost (Per Hour)
2 STIHL 028 chainsaws	\$404 each	\$0.30/SMH	\$0.69/SMH
1 Maintenance Van	Rented	\$0.205/km	\$0.16/km
1 John Deere 2130 Farm Tractor 75 HP Diesel	\$10,690 (used)	\$1.47/PMH	\$3.05/PMH
1 Massey Ferguson 135 Farm Tractor	Rented	\$5.00/PMH (8 PMH/day)	\$4.71/PMH
1 Tree Farmer CD Cable Skidder	Rented	\$3.81/SMH	\$3.81/SMH
1 FARMI JL30 Winch	Rented	\$1.13/SMH	---
1 BRUKS 720 Tractor- Mounted Chipper	--	\$1.66/SMH	\$1.25 SMH
		Average cost for Gagetown site	\$12.66/Gr. tonne
1 Ro-Ro Container Truck Plus 2 Containers on Reserve	Purchased Service	Average cost for UNB Woodlot Site	\$6.56/Gr. tonne

SMH = scheduled machine-hours

PMH = productive machine-hours

Table 7.2
Summary of Cost of Operation
Private Woodlot (Slash 1)

COMPONENT COST	COST BASIS		AMOUNT
Labour ^a	121.07 man-hours	wt. av. labour rate: \$7.40/hr.	\$ 895.92
Equipment			
100 HP Skidder	Fixed Cost	\$5.63/PMH x 30.4 PMH	171.15
Model C5D	Operating Cost	\$5.63/PMH x 30.4 PMH	171.15
Chain Saws	Fixed Cost	\$0.30/SMH x 56 SMH x 2	33.60
	Operating Cost	\$0.69/SMH x 56 SMH x 2	77.28
Tractor - Massey	Fixed Cost	\$1.65/PMH x 12 PMH	19.80
Ferguson Model 165	Operating Cost	\$3.35/PMH x 12 PMH	40.20
Bruks 720 Chipper	Fixed Cost	\$1.50/SMH x 56 SMH	84.00
	Operating Cost	\$1.00/SMH x 56 SMH	56.00
Transportation	13.04 Tonnes x \$18.60/Tonne		242.54
	(20% MC Basis)		
Average Cost/Tonne	= $\frac{1,791.64}{13.04}$		
(20% MC Basis)	= \$137.40/Tonne		
	TOTAL COST		\$1,791.64

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.3
Summary of Cost of Operation
Private Woodlot (Slash 2)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	88.8 man-hours wt. av. labour rate: \$7.40/hr.	\$ 657.12
Equipment		
Tractor - Massey Ferguson Model 135	Fixed Cost Operating Cost \$1.65/PMH x 43.6 PMH \$3.35/PMH x 43.6 PMH	71.94 146.06
Farmi Winch JL30	Total Cost \$1.13/SMH x 40 SMH	45.20
Bruks 720 Chipper	Fixed Cost Operating Cost \$1.50/SMH x 40 SMH \$1.00/SMH x 40 SMH	60.00 40.00
Tractor - Massey Ferguson Model 165	Fixed Cost Operating Cost \$1.65/PMH x 43.6 PMH \$3.35/PMH x 43.6 PMH	71.94 146.06
Chain Saws	Fixed Cost Operating Cost \$0.30/SMH x 40 SMH x 2 \$0.69/SMH x 40 SMH x 2	24.00 55.20
Transportation	7.93 Tonnes x \$18.60/Tonne (20% MC Basis)	147.50
Average Cost/Tonne (20% MC Basis)	$= \frac{1,465.02}{7.93} = \$184.74/\text{Tonne}$	TOTAL COST \$1,465.02

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.4
Summary of Cost of Operation
UNB Woodlot (Thin 1)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	245.5 man-hours wt. av. labour rate: \$7.40/hr.	\$1,816.70
Equipment		
Tractor - Massey Ferguson Model 135	Fixed Cost Operating Cost \$1.65/PMH x 38.9 PMH \$3.35/PMH x 38.9 PMH	64.19 130.32
Farmi Winch JL30	Total Cost \$1.13/SMH x 109 SMH	123.17
Tractor - Massey Ferguson Model 165	Fixed Cost Operating Cost \$1.65/PMH x 22.2 PMH \$3.35/PMH x 22.2 PMH	36.63 74.37
Bruks 720 Chipper	Fixed Cost Operating Cost \$1.50/SMH x 40 SMH \$1.00/SMH x 40 SMH	60.00 40.00
Chain Saws	Fixed Cost Operating Cost \$0.30/SMH x 109 SMH x 2 \$0.69/SMH x 109 SMH x 2	65.40 150.42
Transportation	Total Cost \$10.00/hr. x 40 hours	400.00
	TOTAL COST	\$2,961.20
Average Cost/Tonne (20% MC Basis)	= $\frac{2,961.20}{14.94}$ = \$198.21/Tonne	

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.5
Summary of Cost of Operation Had Objectives Been Only Chip Production
UNB Campus (Thin 2)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	452.7 man-hours wt. av. labour rate: \$7.40/hr.	\$3,349.98
Equipment		
John Deere 2130 Farm Tractor	Fixed Cost Operating Cost \$1.47/PMH x 57 PMH \$3.05/PMH x 57 PMH	83.79 192.66
Bruks 720 Chipper Arvin Chipper	Fixed Cost Operating Cost \$1.66/SMH x 150 SMH \$1.25/SMH x 150 SMH	249.00 187.50
Yankee Yarder	Fixed Cost Operating Cost \$0.07/SMH x 150 SMH \$0.09/SMH x 150 SMH	10.50 13.24
2 Chain Saws	Fixed Cost Operating Cost \$0.30/SMH x 150 SMH \$0.69/SHM x 150 SMH	45.00 103.50
Transportation	34.00 tonnes x \$17.70/tonne	601.80
TOTAL COST		\$4,836.97
Average Cost/Tonne (20% MC Basis)	$= \frac{4,836.97}{34.00} = \$142.26/\text{Tonne}$	

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.6
Summary of Cost of Operation
CFB Gagetown, Hersey Rd. (Clear 1)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	42 man-hours - working foreman 98 man-hours - 2 labourers Total man-hours = 140 Wt. Av. labour rate : \$7.40/hr.	\$1,034.82
Equipment		
2 Chain Saws	Fixed Cost \$0.30/SMH x 75 SMH x 2 Operating Cost \$0.69/SMH x 75 SMH x 2	45.00 103.50
Maintenance Van	Fixed Cost \$0.205/km x 946 km Operating Cost \$0.16/km x 946 km	194.04 152.88
John Deere 2130 Farm Tractor	Fixed Cost \$1.47/PMH x 27.1 PMH Operating Cost \$3.05/PMH x 27.1 PMH	39.84 82.60
Farm J.L. 30 Winch	Total Cost \$1.13/SMH x 75 SMH	84.75
Bruks 720 Chipper	Fixed Cost \$1.66/SMH x 75 SMH Operating Cost \$1.25/SMH x 75 SMH	124.50 93.75
Transportation		
Container Service (58 km one-way distance to delivery location)	Total Cost \$12.66/G. Tonnes x 21.4 G. Tonnes	270.93
	TOTAL COST	\$2,226.61
Average Cost/Tonne (20% MC basis)	= $\frac{2,226.61}{13.44}$ = \$165.67/Tonne	

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.7
Summary of Cost of Operation
CFB Gagetown, Hersey Rd. (Clear 2)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	19 man-hours - working foreman 50 man-hours - 2 labourers 16 man-hours - skidder operator Total man-hours = 85 Wt. Av. labour rate : \$7.40/hr.	\$ 629.00
Equipment 2 Chain Saws	Fixed Cost Operating Cost \$0.30/SMH x 34 SMH x 2 \$0.69/SMH x 34 SMH x 2	20.40 46.92
Maintenance Van	Fixed Cost Operating Cost \$0.205/km x 428 km \$0.16/km x 428 km	87.78 69.16
John Deere 2130 Farm Tractor	Fixed Cost Operating Cost \$1.47/PMH x 16.6 PMH \$3.05/PMH x 16.6 PMH	24.40 50.58
Tree Farmer C4D Skidder	Fixed Cost Operating Cost \$3.81/SMH x 16 SMH \$3.81/SMH x 16 SMH	60.96 60.96
Bruks 720 Chipper	Fixed Cost Operating Cost \$1.66/SMH x 34 SMH \$1.25/SMH x 34 SMH	56.44 42.50
Transportation Container Service (58 km one-way distance to delivery point)	\$12.66 G. tonne x 21.31/G. tonnes	269.78
Average Cost/Tonne (20% MC basis)	= 1,418.88 13.63	TOTAL COST \$1,418.88

= \$104.10/Tonne

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.8
Summary of Cost of Operation
CFB Gagetown, Hersey Rd. (Clear 3)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	27 man-hours - working foreman 64 man-hours - 2 labourers 16 man-hours - skidder operator Total man-hours = 107 Wt. Av. labour Rate : \$7.40/hr.	\$ 791.80
Equipment 2 Chain Saws	Fixed Cost Operating Cost \$0.30/SMH x 40 SMH x 2 \$0.69/SMH x 40 SMH x 2	24.00 55.20
Maintenance Van	Fixed Cost Operating Cost \$0.205/km x 736 km \$0.16/km x 736 km	150.81 118.82
John Deere 2130 Farm Tractor	Fixed Cost Operating Cost \$1.47/PMH x 12.1 PMH \$3.05/PMH x 12.1 PMH	17.79 36.85
Tree Farmer C4D Skidder	Fixed Cost Operating Cost \$3.81/SMH x 16 SMH \$3.81/SMH x 16 SMH	60.96 60.96
Farmi JL 30 Winch	Total Cost \$1.13/SMH x 16 SMH	18.09
Bruks 720 Chipper	Fixed Cost Operating Cost \$1.66/SMH x 40 SMH \$1.25/SMH x 40 SMH	66.40 50.00
Transportation Container Service (58 km one-way distance to delivery point)	Total Cost \$12.66/G. tonne x 15.65 G. tonnes	198.03
Average Cost/Tonne (20% MC basis)	= $\frac{\$1,649.71}{10.04}$ = \$164.31/Tonne	TOTAL COST \$1,649.71

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.9
Summary of Cost of Operation
UNB Woodlot (Clear 4)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	50 man-hours - working foreman 114 man-hours - 2 labourers Total man-hours = 164 Wt. Av. labour rate : \$7.40/hr.	\$1,213.60
Equipment 2 Chain Saws	Fixed Cost Operating Cost \$0.30/SMH x 58 SMH x 2 \$0.69/SMH x 58 SMH x 2	34.80 80.04
Maintenance Van	Fixed Cost Operating Cost \$0.205/km x 621 km \$0.16/km x 621 km	127.38 100.36
John Deere 2130 Farm Tractor	Fixed Cost Operating Cost \$1.47/PMH x 24.2 PMH \$3.05/PMH x 24.2 PMH	35.57 73.72
Farm JI 30 Winch	Total Cost \$1.13/SMH x 58 SMH	65.54
Massey Ferguson 135 Tractor (Rental)	Fixed Cost Operating Cost \$5.00/SMH x 64 SMH \$4.71/SMH x 64 SMH	320.00 301.44
Bruks 720 Chipper	Fixed Cost Operating Cost \$1.66/SMH x 58 SMH \$1.25/SMH x 58 SMH	96.28 72.52
Transportation Container Service (18 km one-way distance to delivery point)	Total Cost \$6.56/G. tonne x 20.6 G. tonnes	135.29
Average Cost/Tonne (20% MC basis)	= $\frac{2,656.54}{13.80}$ = \$192.50/Tonne	TOTAL COST \$2,656.54

^a Excludes travelling time and data collection time.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.10
Summary of Cost of Operation
UNB Woodlot (Clear 5)

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	25.5 man-hours - working foreman 65 man-hours - 2 labourers Total man-hours = 90.5 Wt. Av. labour rate : \$7.40/hr.	\$ 669.70
Equipment 2 Chain Saws	Fixed Cost Operating Cost \$0.30/SMH x 30 SMH x 2 \$0.69/SMH x 30 SMH x 2	18.00 41.40
Maintenance Van	Fixed Cost Operating Cost \$0.205/km x 726 km \$0.16/km x 726 km	148.83 117.26
John Deere 2130 Farm Tractor	Fixed Cost Operating Cost \$1.47/PMH x 15.6 PMH \$3.05/PMH x 15.6 PMH	64.33 47.53
Massey Ferguson 135 Tractor (Rental)	Fixed Cost Operating Cost \$5.00/SMH x 30.0 SMH \$4.71/SMH x 30 SMH	150.00 141.30
Bruks 720 Chipper	Fixed Cost Operating Cost \$1.66/SMH x 30 SMH \$1.25/SMH x 30 SMH	49.80 37.50
Transportation Container Service (18 km one-way distance to delivery point)	Total Cost \$6.56/G tonne x 23.2 G. tonnes	152.58
Average Cost/Tonne (20% MC basis)	= 1,638.23 15.36	TOTAL COST \$1,638.23
	= \$106.66/Tonne	

^a Excludes travelling time and data collection time.

Includes Farmi JL 30 winch.

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.11
Summary of Cost of Operation Where Major Objective was Thinning
UNB Campus (THIN 2)

COMPONENT COST	COST BASIS	AMOUNT
Labour	Applied to thinning	\$ 0.00
Equipment		
John Deere 2130	\$1.47/PMH x 57 PMH	83.79
Farm Tractor	\$3.05/PMH x 57 PMH	192.66
Bruks 720 Chipper,	\$1.66/SMH x 150 SMH	249.00
Arvin Chipper	\$1.25/SMH x 150 SMH	187.50
Yankee Yarder	Applied to thinning	0.00
2 Chain Saws	Applied to thinning	0.00
Transportation	34.00 tonnes x \$17.70/tonne	601.80
Average Cost/Tonne (20% MC basis)	= \$ 38.67/Tonne	

SMH = Scheduled Machine-Hour

PMH = Productive Machine-Hour

Table 7.12
Summary of Cost of Operation
Drying, Processing and Delivery

COMPONENT COST	COST BASIS	AMOUNT
Labour ^a	Total man-hours = 585 wt. av. labour rate: \$7.40/hr.	4,329.00
Equipment		
Processing Facility ^b	Depreciation: Straightline, 25 yr. life Cost: \$44,000. No Salvage Value Electric Power: 600 KWH @\$0.04/KWH 37 loads/yr.	1,760.00 880.00
John Deere 2130 Farm Tractor	Depreciation: Straight line, 5 yr. life Cost \$14,000. No Salvage Value \$3.05/PMH x 189 PMH	2,800.00 576.00
Delivery Truck	4 tonnes/load, 40 homes 10 tonnes/home, av. distance 12 km. \$1.25/km	3,600.00
	TOTAL COST	\$13,945.00
Average Cost/Tonne (20% MC Basis)	= $\frac{13,945.00}{440}$ = \$31.69/tonne	

^aIncludes both processing and delivery time.

^bAssumed capacity 440 tonnes/yr.
Equivalent to 40 homes @ 10 tonnes/yr.

PMH = Productive Machine-Hour

Table 7.13. Fuel wood chip production total cost for each block harvested, with cost percentages applied to the separate components of the total cost.

Block	\$/Tonne	Labor	Equipment		Transporation
			Fix	Oper.	
SLASH 1	\$137.40	50	17	19	14
SLASH 2	184.74	45	19	26	10
THIN 1	198.21	61	12	13	14
THIN 2 ¹	142.26	69	9	10	12
THIN 2 ²	36.67	-	-	-	-
CLEAR 1	165.67	46	22	19	12
CLEAR 2	104.10	44	18	19	19
CLEAR 3	164.31	48	20	20	12
CLEAR 4	135.81	46	25	24	5
CLEAR 5	106.66	41	26	24	9
Average	148.79	50	19	19	12

¹Costed on same basis as other blocks. Included in averages.

²As experienced. Not included in averages.

ECONOMICS AND FUTURE CONSIDERATIONS

Based on the actual experience of the 9 harvesting blocks contained in this demonstration project, Chapter 7.0 illustrates that the cost of labour involved in the harvesting, handling and chipping process is clearly the most significant cost item, representing 50% of the total cost of producing chips from the stump area to some central storage plant. It is clear, therefore, that there is a need for very careful planning of the harvesting procedures and that a higher degree of mechanization and equipment utilization will produce the lowest cost per tonne, assuming that transportation does not play a more significant role than the average 12% cost experienced in the demonstration project.

With higher volume production on a longer time-scale, the operating crew can become familiar with the equipment and process and can take advantage of the learning curve which comes from operating in one type of stand over a period of time. This results in the lowering of the average cost per-tonne figure. This higher level of production would require a market made up of a large number of private residences located in a narrow geographic area or a market consisting of a small number of higher volume users. Aside from the individual residence market, the potential for small-scale operations appears to focus on applications such as green houses, multiple farm buildings (poultry, hogs, beef and dairy producers), small commercial buildings such as shopping plazas and service and maintenance operations, government buildings such as liquor stores, and marketing board operations.

In addition to the higher replacement volume of oil by wood chips, the above application areas have another advantage over individual residences; the larger users have access to capital required to make the change-over from a conventional heating system to a wood chip heating system, including the purchase of a suitable furnace and controls and the installation of storage and drying facilities for wood chips. At the present time, wood chip heating equipment remains more costly for the same energy equivalent than either electricity or fuel oil-fired systems, basically because of the volume production enjoyed by the more conventional systems as a result of many years of low-cost conventional fuels. Another reason for suggesting the use of wood chips in the applications outlined is that at least some of those potential users may already have suitable harvesting equipment required for their daily operations but not fully utilized on a year-round basis. Typical of these users are farms, greenhouses and other small commercial operations. It was shown in the previous chapter that ownership costs or fixed capital costs represented approximately 19% of total harvesting costs. The only additional machinery item unlikely to be already available would be the small-scale chipper. Large-scale chippers similar to those used by forestry companies as part of the manufacturing process for the production of pulp and paper are clearly outside the range anticipated by the small-scale technology being demonstrated in this project.

Even small-scale chippers, as used in this project, have the potential to produce enough chips in one day to supply the needs of a normal residence for one year. Therefore, it is unlikely that any individual would purchase such a chipper unless it was being bought with the intent of renting it out, as is done with wood splitting equipment from rental agencies.

On the other hand, the chipper could be purchased by a cooperative venture. Either way, the potential market must be sufficient to justify an expenditure in the order of \$10,000 so that the return on the capital investment can be recovered in a reasonable time frame. Current interest rates on borrowed capital and rental rates for similar pieces of equipment indicate that a rental rate of between \$80 and \$100 per day would be appropriate. The ready availability of small-scale chippers at the present time is probably one of the major hurdles which must be overcome if wood chips are to become a viable alternative fuel.

Another, but less significant, problem is the drying and storage of wood chips prior to use. From the point of view of safety and maximum combustion efficiency, wood chips at 20% moisture content are optimum. While this project has been demonstrating a central storage and drying plant, it is probable that a simple, inexpensive drying bin, which doubles as a storage facility, could be constructed by individual users. This might require a stand-alone facility or some modification to an existing home or building. In the future one could even anticipate drying and storage facilities being designed into a new installation or home where wood chip technology was to be installed.

A further factor which may limit the use of wood chip technology to a few specialized areas of application is that the chip burning equipment itself is still under development, both domestically and internationally; while certain types of businesses might be attracted by the potential for cost savings, the individual homeowner; in particular, will have to be convinced that a chip furnace supplies the same convenience factor as is now enjoyed by conventional fuel such as electricity and fuel oil.

From a purely economic viewpoint, a number of scenarios are suggested which offer a variety of capital expenditure and saving situations. These have been illustrated by calculating the return on investment (ROI) for various combinations of assumptions. Table 8.1 shows the cost of chips to the point of storage, as demonstrated by this project, with alternative costs for those situations where no labour costs are involved and where no labour or other fixed costs are involved. This may be the case where an individual can rely on free help from family members or friends and where some or all of the machinery is already available as a result of farming or similar needs. In this latter situation, chip product costs can be reduced to approximately one-third that of the fully-costed production process.

Table 8.2 illustrates the annual savings possible when a homeowner is making a decision between the use of fuel oil and wood chips. Note that at the highest and average harvesting costs from this project, no savings accrue, but at the lowest cost (CLEAR 2) a small savings results. This saving becomes significant when the integrated cost (THIN 2) is considered. Savings are also possible when labour and fixed costs are absorbed by the homeowner. Figure 8.1 illustrates these savings over a range of energy consumptions.

Table 8.3 illustrates the situation where the homeowner is considering a new installation. Here, the rate of return approximates the current interest rate on borrowed money (14.0%) at the tenth year. Table 8.4 carries this one step further by outlining the same situation, but where replacement of existing equipment is contemplated. Assuming the homeowner qualifies for a grant under the COSP program, the rate of return is much more favourable, approximating current interest rates at the fourth year.

Table 8.5 illustrates the situation for a small business enterprise now using 9,000 litres (2000 Imp gal) of fuel oil per year and contemplating a new installation. The return on this investment would occur at approximately three and a half years and would be very justified at five years.

Table 8.6 illustrates the situation where the homeowner cannot produce any portion of the chips required and must purchase chip fuel from a retailer in the same manner as fuel oil is now purchased.

The average cost of fuel chips (\$148.79/tonne produced), plus the additional cost of \$31.69 for the processing, drying and delivery requirements, does not result in substantial savings until the integrated cost (THIN 3) is reached. However, if commercial production of wood chips was commenced, it can be assumed that savings resulting from scale of operations and improved methods could result in a 30% to 50% improvement in the average cost, making wood-chips a viable alternative fuel to the city dweller.

At the present level of development, there appears only limited justification for producing or heating with wood chips. Their economic feasibility depends upon such factors as access to a woodlot, a trailer and other equipment, a barn or other storage facility, free labour, and - in the case of the producer - a market. However, wood chip production may prove an important spinoff of increased silvicultural treatment of all forests; woodlot improvement though practices such as thinning and clearing can have added value if the resultant material is converted to an alternative, renewable fuel source. The production of this alternative fuel could contribute to our increasing self-sufficiency with respect to imported oil and its skyrocketing cost.

In addition to developments in forest management and changing oil economics, government incentives could play an active role in stimulating entrepreneurs to enter the wood chip market on a vertically-integrated basis - that is, to not only supply furnaces, stokers and drying equipment, but also to produce and deliver the fuel chips. Through this approach, wood chip production and technology could become as viable an enterprise in future as the fuel oil business is today.

Table 8.1. Cost per tonne of chips delivered to storage including all costs and excluding labour and fixed costs for comparison.

Block	Total	Costs, \$	
		No Labour	No labour and no fixed
SLASH 1	137.40	68.71	44.94
SLASH 2	184.74	101.89	67.34
THIN 1	198.21	76.64	53.15
THIN 2	142.26 ¹	43.73	32.24
THIN 2	38.67 ²	38.67	28.88
CLEAR 1	165.67	88.70	52.08
2	104.10	57.88	39.55
3	164.31	85.46	51.59
4	135.81	104.50	55.14
5	106.66	63.09	34.90
Average	148.79	76.74	47.88

¹ Costed on same basis as other blocks. Included in averages.

² As experienced. Not included in averages.

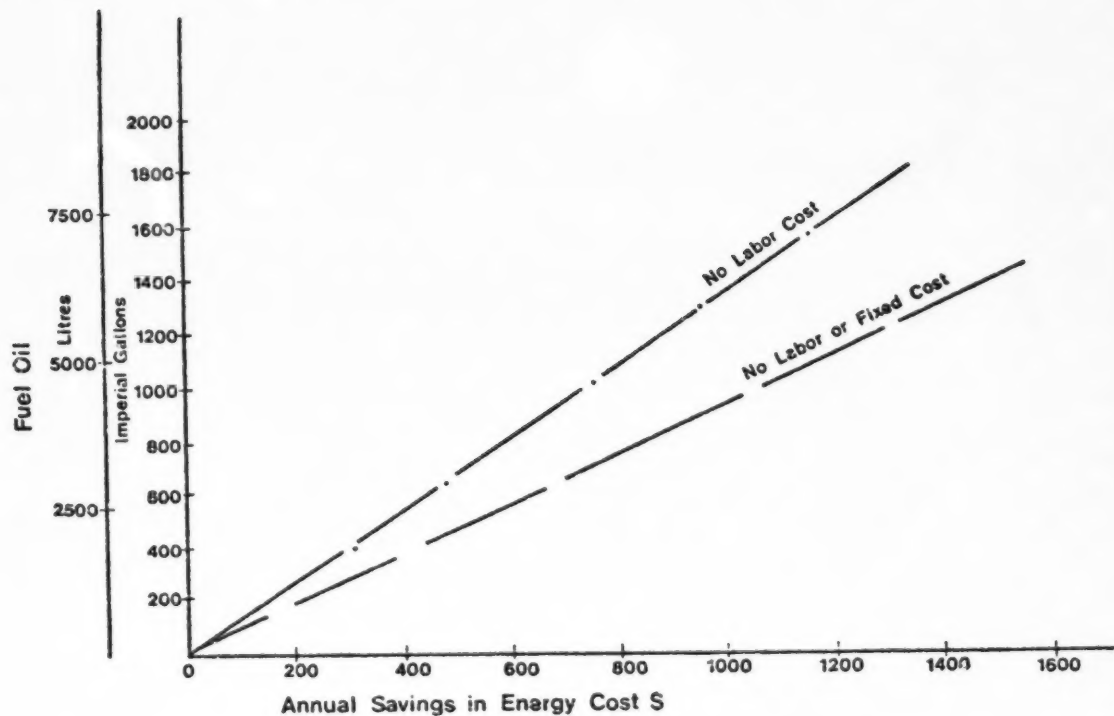


Figure 8.1. Potential savings in heating fuel costs under two harvesting scenarios. This is a graphical illustration of the two other accounting possibilities shown at the bottom of Table 8.1, but over a range of fuel consumptions.

Table 8.2. Several cost possibilities when comparing wood chips to fuel oil for heating a typical home.

<u>Assumptions</u>			
<u>Present oil use</u>	<u>Cost/l</u>	<u>Fuel Bill</u>	<u>Equivalent Chip Quantity</u>
4500/l	\$0.34	\$1,540	11 tonnes at 20% MC

Project Experience and Cost Comparisons

<u>Chip Cost/Tonne</u>	<u>Basis</u>	<u>Cost for 11 Tonnes</u>	<u>Savings Over Oil</u>
\$198.21	Highest Cost (THIN 1)	\$2,180	\$-640
148.79	Average	1,637	-102
104.10	Lowest (CLEAR 2)	1,145	395
38.67	Integrated (THIN 2)	425	1,115

Some Other Accounting Possibilities

<u>11 Tonnes/Cost</u>	<u>Basis</u>	<u>Savings</u>
\$844	Average minus labour	\$ 698
\$527	Average minus labour and fixed costs	1,013

Table 8.3. Return from investment in chip-burning equipment for a home having an 11-tonne chip fuel requirement and installing a new furnace.

<u>Assumptions</u>			
<u>New Chip Furnace Cost</u>	<u>Chip Bin Cost</u>	<u>Total Installation Cost</u>	<u>Savings</u>
\$3,600	\$500	\$5,100	\$1,103/yr.

Return on \$5,100 Investment

<u>Investment Period</u>	<u>Rate of Return</u>
6 years	5.25%
8 years	11.6%
10 years	13.5%
12 years	15.7%

Table 8.4. Return from investment in chip burning equipment for a home having an 11-tonne chip fuel requirement and installing a replacement furnace.

<u>Assumptions</u>				
<u>New Chip Installation</u>	<u>New Oil Furnace</u>	<u>Cost Rebate</u>	<u>Actual Cost</u>	<u>Savings</u>
\$5,100	\$1,400	\$800	\$2,900	\$1,103/yr

Return on \$2,900 Investment

<u>Investment Period</u>	<u>Rate of Return</u>
3 years	2.4%
4 years	14.9%
5 years	22.0%
6 years	26.4%

Table 8.5. Return from investment in chip-burning equipment for a small business enterprise having a 22-tonne chip requirement and installing a new furnace.

<u>Assumptions</u>			
<u>New Chip Furnace</u>	<u>Chip Bin Installation</u>	<u>Total Cost</u>	<u>Savings</u>
\$3,600	\$1,500	\$5,100	\$2,026

Return on \$5,100 Investment

<u>Investment Period</u>	<u>Rate of Return</u>
3 years	9.3%
4 years	21.5%
5 years	28.3%
6 years	32.3%

Table 8.6. Several cost possibilities when comparing wood chips to fuel oil for heating a typical home, assuming chips are delivered.

<u>Present Oil Use</u>	<u>Cost/l</u>	<u>Fuel Bill</u>	<u>Equivalent Chips</u>
4500 l	\$0.34	\$1,540	11 tonnes @20 MC
Chip processing and delivery cost. \$31.69/tonne			

Project Experience and Cost Comparisons

<u>Chip Cost/Tonne Delivered</u>	<u>Basis</u>	<u>Cost for 11-Tonnes</u>	<u>Savings Over Oil</u>
\$229.90	Highest Cost (THIN 1)	\$2,528.90	\$ - 988.90
180.48	Average	1,985.28	- 445.28
135.79	Lowest Cost (CLEAR 2)	1,493.69	46.31
70.36	Integrated (THIN 2)	773.96	766.04

Some Other Accounting Possibilities

<u>11-Tonne Cost</u>	<u>Basis</u>	<u>Savings</u>
\$126.34	30% improvement on average cost	\$150.30
90.24	50% improvement on average cost	547.36

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